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Analyzing Lead Content in the Lehigh River

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by

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Introduction

Lead in drinking water is a concern for many communities, as it can cause serious harmful effects for those exposed to it in high enough concentrations. It usually enters water from three possible sources: from lead pipes near the water supply, from the erosion of sediments that contain lead, or from pollution (*Center for Disease Control and Prevention*, 2016). Lead has emerged recently as a concern in the Lehigh Valley Area due to high concentrations of lead measured in the air in Palmerton by the Environmental Protection Agency (EPA). Lead levels in the air exceeded the national standard, which is a three-month rolling average of 0.15 micrograms per cubic meter, as a result of the operations of the American Zinc Company in Palmerton (*Hedes*, 2018). Lead is also present in the Palmerton area in waste rock and slag piles that were left behind by the New Jersey Zinc Company's ore processing plants that shut down in 1980 (*Times News,* 2018). Emissions from these processing plants caused defoliation of about 2,000 acres of Blue Mountain, and operations left behind a legacy of high concentrations of metals in the surface sediments (*United States Environmental Protection Agency*, n.d. a.). The lead and other chemicals from this site also entered the air, Aquashicola Creek, and the Lehigh River (*Time News,* 2018).

The EPA found concentrations of lead in the waters at Glendon, PA, which is downstream from Palmerton along the Lehigh River. However, lead was not found farther north of Palmerton, prompting the Department of Environmental Protection (DEP) to look for a potential source in the Palmerton area. Preliminary measurements from the EPA have shown that there is lead present in the Lehigh River, but the concentrations do not exceed the action level of 15 ppb (*United States Environmental Protection Agency*, n.d. b). However, lead is still present at low concentrations, and continuous or chronic exposure to lower concentrations of lead may impair aquatic organisms (*Greene*, 2014).

The concentrations of other elements and their correlations to lead, as well as the concentrations of lead itself, can be used to study the source of the lead and whether it comes from pollution or sediments using the process called elemental fingerprinting. If the lead correlates with anthropogenic elements, this could indicate that it is travelling from an anthropogenic source.

Lead and other anthropogenic elements travel in the water in both dissolved and particulate forms. The dissolved form of an element is of a much smaller size than the particulate and is able to pass through a filter (*Bruckner*, 2016). For instance, if a 0.2 μm filter is used, the dissolved lead will remain in the sample after filtration because it has a particule size smaller than 0.2 μm. The particulate lead has a particle size larger than 0.2 μm and does not pass through it. Lead can also be converted from a dissolved to particulate form. Particulate lead is bound to other surfaces, whereas the dissolved simply remains in the water. Dissolved lead can replace the bonding of other elements on a surface, such as hydrogen ions, and in doing so become particulate lead as shown in the figure below. The dissolved, particulate, and total concentrations of lead and other elements can be measured to determine in what forms they are travelling.

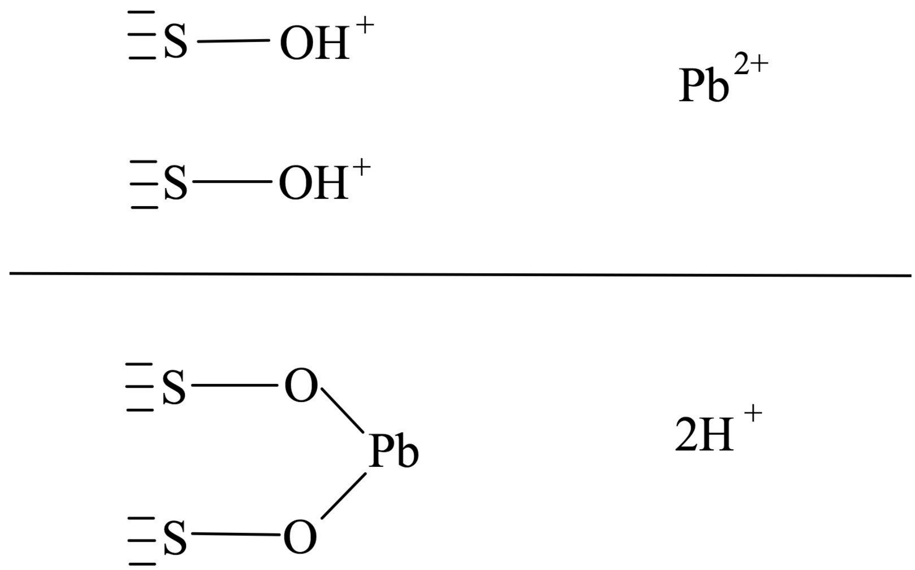


Figure 1: The conversion from dissolved lead (Pb^{2+}) to particulate lead occurs by lead bonding to a surface (S) in the place of hydrogen (H^{+}) ions.

The concentration of lead can also be studied in relation to human and aquatic organism health. This is accomplished by calculating the hardness of the water, which is a measure of its concentrations of magnesium and calcium (*United States Geological Survey*, n.d. a). Calcium mitigates lead's harmful effects by preventing the body from uptaking lead (*Simons*, 1988), so a greater calcium concentration and thus higher hardness will allow a greater concentration of lead to be present in the water without it being harmful to organisms. This hardness can be used to determine chronic and acute toxicity. Acute toxicity causes damage rapidly, while chronic toxicity takes longer to do damage. For fish, acute toxicity can do damage within the first two to four days of exposure (*Sprauge*, 1969).

The main source of the concentration of lead currently observed in the Lehigh River was unknown, and the main goal of this research was to determine the source of the aqueous lead and to identify potential organisms that will be affected. Where the lead is potentially coming from and what elements it correlates with were determined. Where and when the lead concentration exceeds the health criteria for humans and aquatic animals was also determined. The data was analyzed from the sample sights along the Lehigh River downstream of Palmerton, which is pictured below in figures 2 and 3.

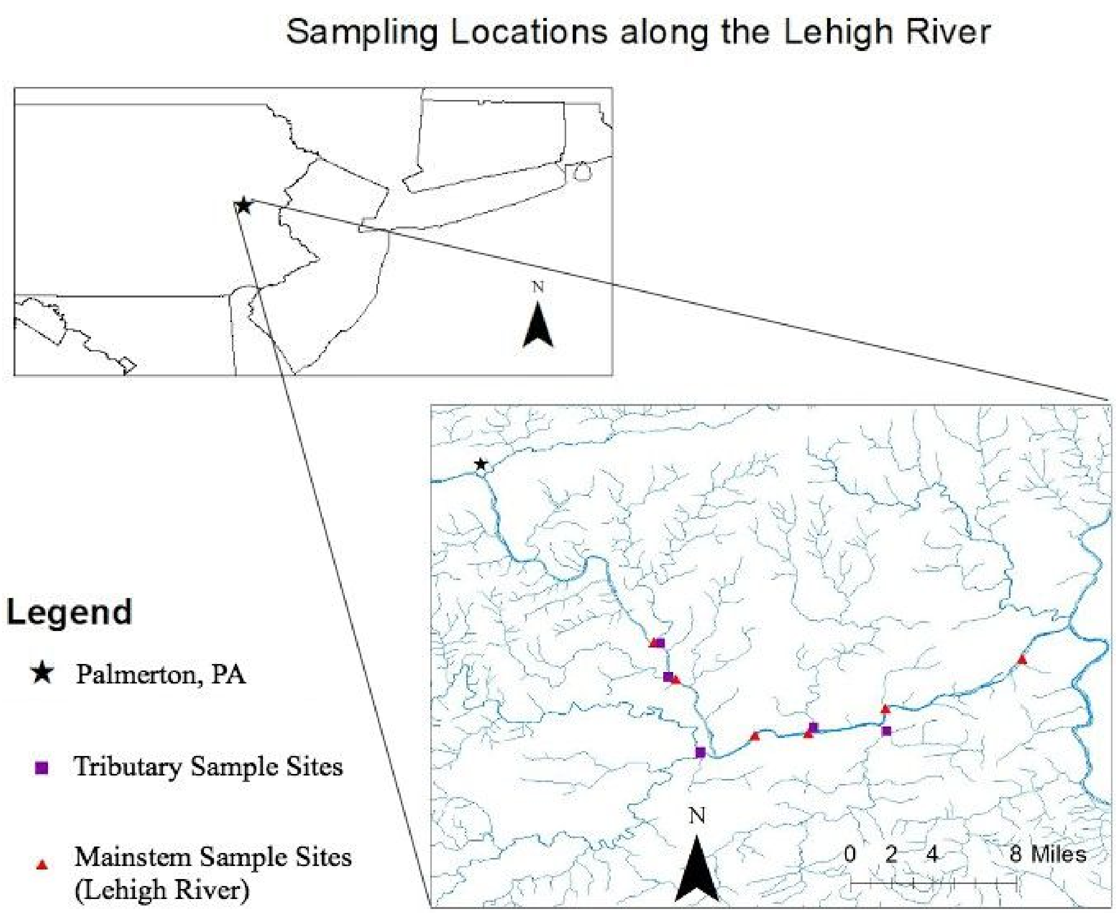


*Figure 2: The locations of the sampling sites are shown. The mainstem samples are located along the Lehigh River, and the tributary samples are located at several creeks that feed into the Lehigh River (*United States Census Bureau*, n.d.,* PASDA*, n.d.).*

Sampling Locations along the Lehigh River

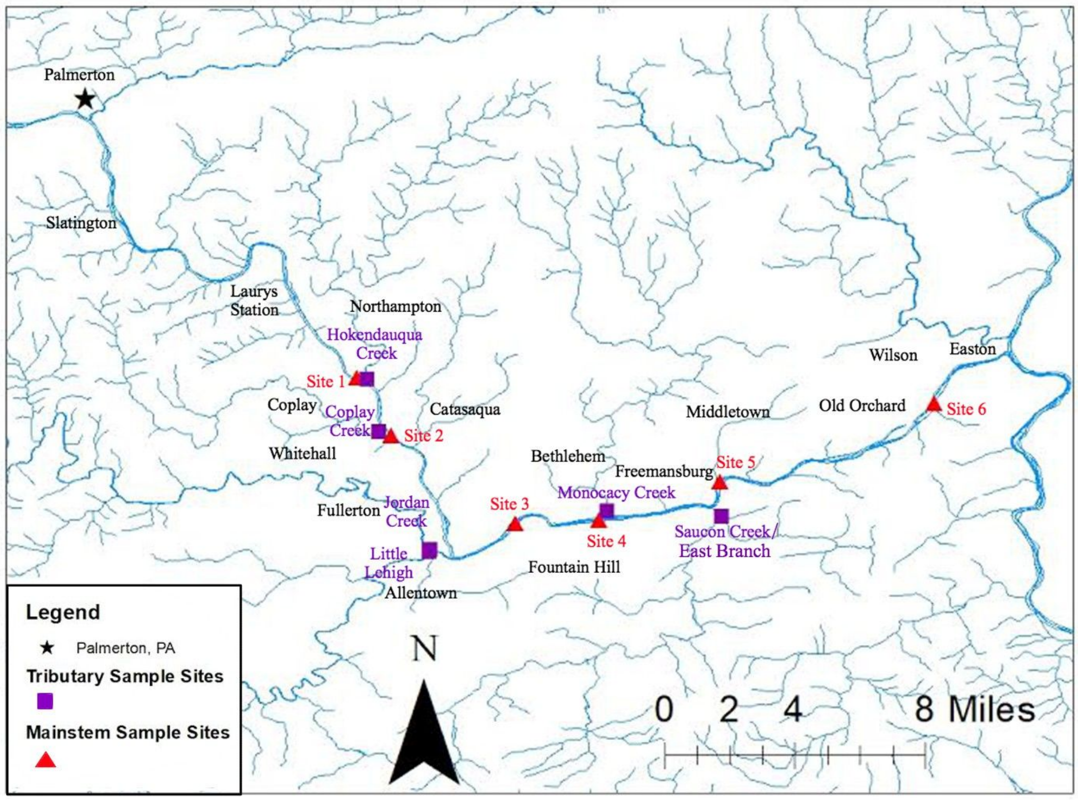


*Figure 3: A closer look at the sampling locations. The sample site names along the Lehigh River are labeled, as are the sampled tributaries. The boroughs and cities near the sample sites are also labeled (*United States Census Bureau*, n.d.,* PASDA*, n.d.).*

Methods and Materials

A team of scientists from the DEP went out to sites along the Lehigh River and its local tributaries on three different dates: June 19, July 2, and July 19, 2018. On each date, two samples were collected from each site. One sample underwent syringe filtration, during which the water passed through a 0.2 μm filter so that the particulate element concentrations were removed and only those that were dissolved remained. This gave a "dissolved" sample, while the second sample did not undergo the process. The second samples contained both the dissolved and particulate element concentrations, and were called the "total." The "particulate" concentrations were then found using the equation:

$$Particulate = Total - Dissolved \quad (1)$$

These samples were then analyzed in the lab. Lead and other elements in the water were detected using inductively coupled plasma mass spectrometry (ICP-MS), which breaks up a liquid into an aerosol and then ions. These ions were then sorted by mass and charge and then detected and converted into a concentration for the corresponding elements (*Thomas*, 2004). This process allowed for the detection of lead and other elements in water samples, and it was used to determine in what concentrations these elements are present (*Spectroscopy Editors*, 2007). The samples from the first two sampling rounds were run by Lehigh University's instruments, while the ones from the third round of sampling were run by the DEP. The data from the ICP-MS was then analyzed in Excel to determine any relationships between the concentrations of elements in the samples and their respective sampling site locations.

Once imported into excel, the data was organized by sample site into dissolved, particulate, and total lead concentrations. The amount of dissolved lead present versus the amount of particulate lead present was analyzed.

Next, the channel distance to each site from Palmerton was approximated using Google Earth. The lead contents of the samples taken from the Lehigh River were then plotted against the channel distance from Palmerton to each site to determine any relationships between the lead concentrations and the location along the Lehigh River. The data underwent a linear regression analysis and p-value tests at a significance level of 0.05 to determine if the trend between lead concentration and distance from Palmerton was statistically significant.

The correlations between lead and other elements for the Lehigh River samples were found by linear regression analyses. Zinc was focused on and graphed against the lead concentrations, as it is expected to travel with the lead down the Lehigh River if the zinc companies in Palmerton are the source. Linear regression analyses and p-values tests were used to determine if these correlations were statistically significant.

The correlations between dissolved and particulate values of lead with aluminum, manganese, and iron were also examined for the Lehigh River samples. Linear regression analyses and the p-value tests with a significance level of 0.05 were also conducted.

The flux values of each element were also calculated using the discharge values of the Lehigh River and its tributaries. The mean annual discharge values for the Lehigh River gages were found on the United States Geological Survey website, as were some of the tributary discharge values. For the tributaries that did not have mean annual discharge data available on the U.S. Geological Survey website (*U.S. Geological Survey* n.d. b), Google Earth and CalTopo (*Caltopo* n.d.) were used to calculate the discharge. First, the hydraulic radius was calculated using the equation (*Fetter*, 2001):

$$Hydraulic\ Radius = \frac{cross{-}sectional\ area}{wetted\ perimeter} \quad (2)$$

The cross-sectional area was determined by multiplying the tributaries' depth by their width, while the wetted perimeter was calculated by multiplying the depth by 2 and adding that to the width (*Fetter*, 2001).

The width was found using Google Earth and CalTopo (*Caltopo* n.d.), and the depth was set at a value of 1 meter for the Hokendauqua, Coplay, Jordan, Little Lehigh, Monocacy, and Saucon creeks, while 0.5 meters was used for the East Branch of Saucon Creek. From there, the tributaries' slope was calculated by finding the elevation of two points and the distance between them. The slope equation was then used:

$$Slope = \frac{elevation\ 1 - elevation 2}{distance} \qquad (3)$$

The absolute value of the slope was then taken and used to find the velocity with the equation (*Manning*, 1891):

$$V = \frac{1}{n} R^{2/3} S^{1/2} \qquad (4)$$

where V is the velocity, R is the hydraulic radius, and S is the slope. An n value of 0.4 was used. The known discharge value for Saucon Creek was about 2 m^3/sec, and this value for n gave a discharge value within the range. As such, it was used for the rest of the creek calculations that were not known. However, it should be noted that this is a very high n to use. The discharge values are approximations to give a visual estimate of flux, and as such the values themselves should not be given too much analysis.

Discharge was calculated using the equation (*United States Geological Survey* n.d. c):

$$Discharge = Area \times Velocity \qquad (5)$$

where the area was calculated by multiplying the tributaries' width and depth.

The discharge rates were converted to Liters per minute and used in the following equation to find the fluxes of lead, zinc, aluminum, manganese, and iron:

$$Flux = \frac{discharge \times concentration(ppb)}{10^{-6}} \qquad (6)$$

Once the flux values were obtained for lead, zinc, aluminum, manganese, and iron at every tributary and sample sites 1, 5, and 6 along the Lehigh River, they were used to create diagrams depicting the fluxes in comparison to each other. The values for each sample site for all three sampling times were averaged together to give one flux for each element at each site. Sample sites 5 and 6 were averaged together to give an ending flux for the sample area of the Lehigh River.

The toxicity levels for the Lehigh River samples and the tributary samples were also calculated. This was accomplished by first finding the hardness of each sample using the equation (*California Water Boards* n.d.):

$$Hardness = (2.5 \times Ca) + (4.1 \times Mg) \quad (7)$$

This gives a hardness in mg/L. Once this hardness was found for each sample, it was converted into a format that could be compared to the lead concentrations using the formula:

$$(1.42603 - [ln(hardness) \times 0.145712]) \times e^{[1.273 \times ln(hardness) - 4.705]} \qquad (8)$$

to get the Criteria of Continuous Concentration for aquatic animals and the formula:

$$(1.42603 - [ln(hardness) \times 0.145712]) \times e^{[1.273 \times ln(hardness) - 1.46]} \qquad (9)$$

to get the Criteria of Acute Concentration for aquatic animals (*United States Environmental Protection Agency*, 1985 and *Missouri Department of Natural Resources*, 207). Note that the only difference in the calculations is in the last number in the exponent, which defines if chronic or acute toxicity is being examined. For the particulate concentrations, the hardness value for the total concentration was used. The sample concentrations were then divided by the criterion concentrations to calculate a Chronic or Acute Toxicity percentage. These values range from

0-100%, with 0% indicating no toxicity and values over 100% indicating likely harmful conditions.

Results

The water samples were taken on three days, the flow conditions of which are shown below:

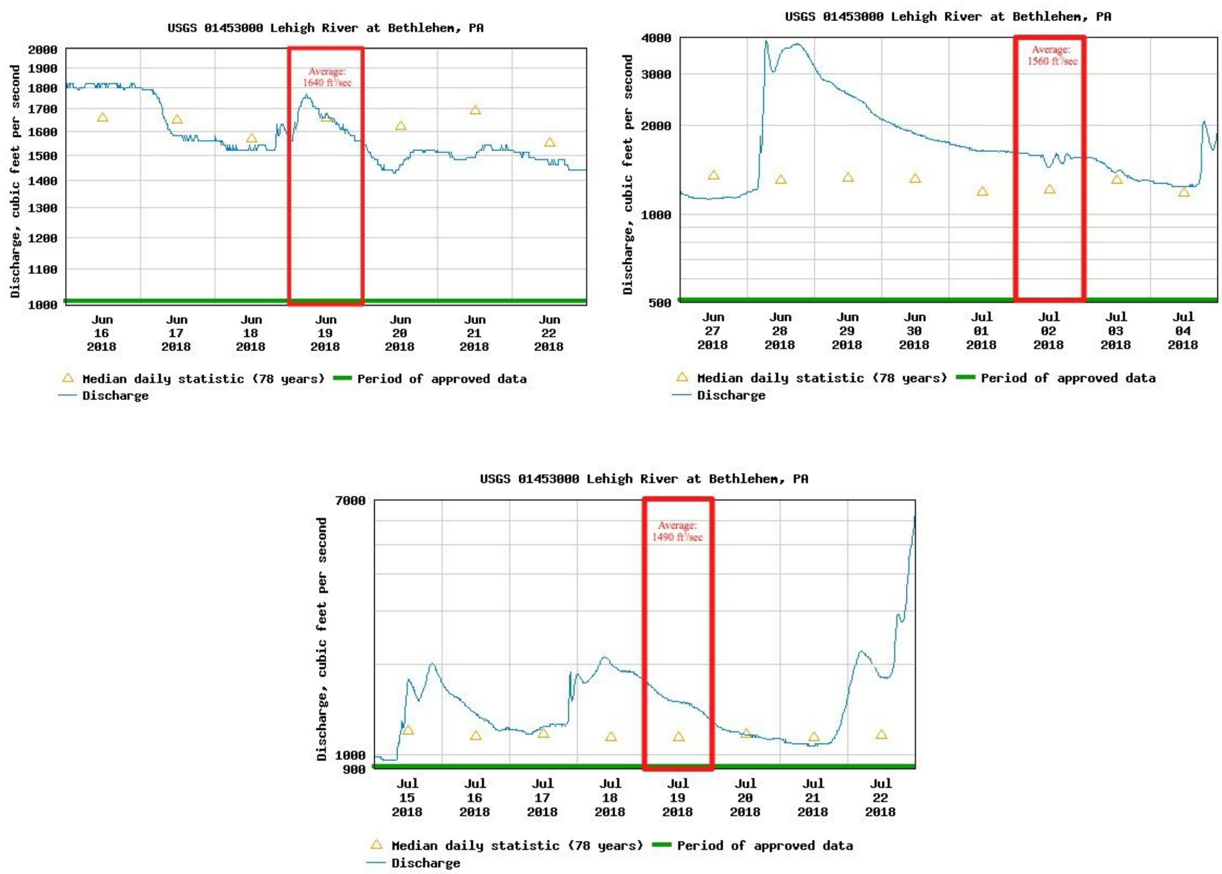


*Figure 4: Discharge of the Lehigh River on June 19, July 2, and July 19, 2019. The red box indicates the day on which the samples were taken, and the yellow triangles indicate the average discharges over the last 78 years (*United States Geological Survey*, n.d. d).*

The flow conditions can also be compared over several months, as shown below:

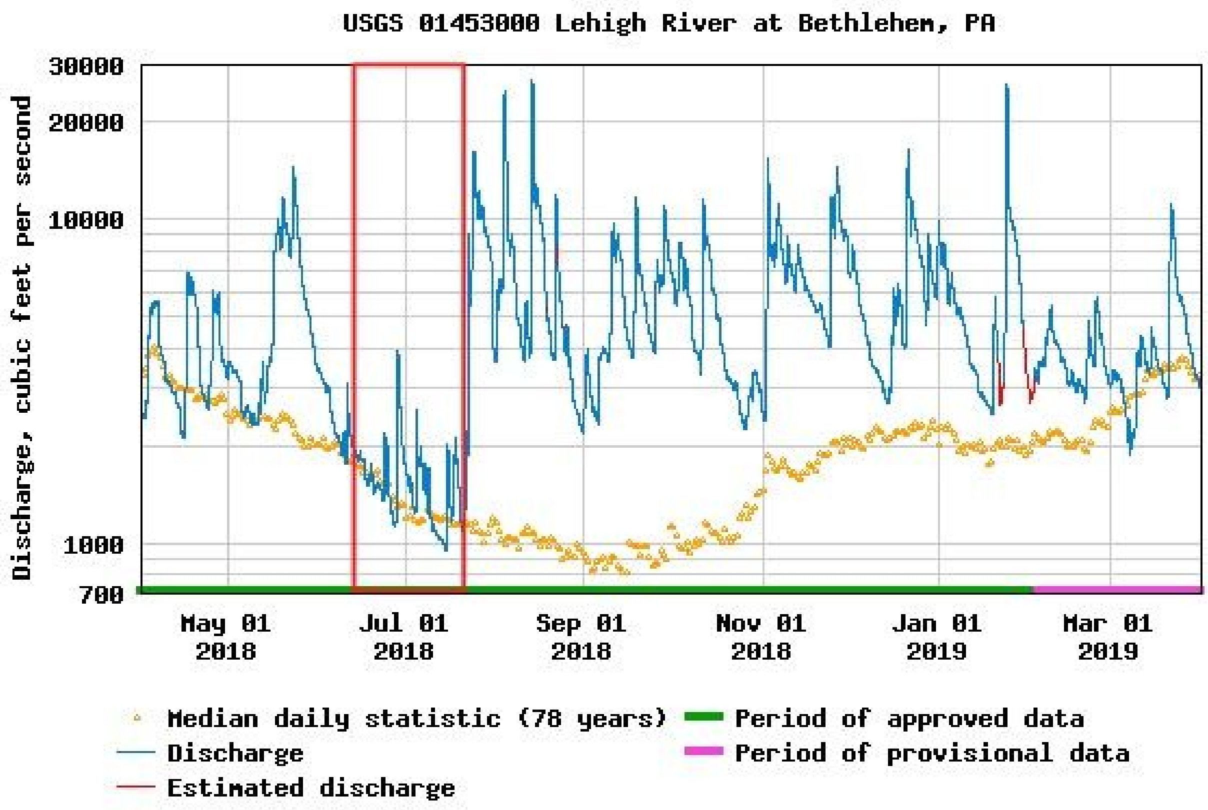


*Figure 5: Discharge rates from May 2018- March 2019. The timeframe in which the samples were taken is shown by the red box, and the yellow triangles indicate the average discharges over the last 78 years (*United States Geological Survey*, n.d. d).*

When the samples were taken, the Lehigh River had an average daily discharge of 1640 ft^3/sec on June 19, 1560 ft^3/sec on July 2, and 1490 ft^3/sec on July 19. The discharge on June 19 falls on the average, whereas the discharges on July 2 and July 19 are slightly above the average. However, compared to the other months shown in figure 5, the discharges for these days are much closer to the average and are much lower than the months following the sampling dates.

Data from each round of sampling was obtained using the ICP-MS and organized into data tables. The data was divided into samples taken from the Lehigh River and samples taken from its tributaries. The lead data obtained from the ICP-MS for the Lehigh River sites, along with location data for each sample, is shown below.

Sample #	**State**	**Date**	**Location**	**Distance**	**Lead**	**Zinc**
2	Dissolved	6/19/18	Lehigh Site 01	22.3	0.359	21.4
2	Particulate	6/19/18	Lehigh Site 01	22.3	0.187	8.90
2	Total	6/19/18	Lehigh Site 01	22.3	0.546	30.3
4	Dissolved	6/19/18	Lehigh Site 02	25.6	0.227	19.3
4	Particulate	6/19/18	Lehigh Site 02	25.6	0.239	4.30
4	Total	6/19/18	Lehigh Site 02	25.6	0.466	23.6
7	Dissolved	6/19/18	Lehigh Site 03	35.6	0.108	11.4
7	Particulate	6/19/18	Lehigh Site 03	35.6	0.143	8.10
7	Total	6/19/18	Lehigh Site 03	35.6	0.251	19.5
7 (duplicate)	Dissolved	6/19/18	Lehigh Site 03	35.6	0.151	11.4
7 (duplicate)	Particulate	6/19/18	Lehigh Site 03	35.6	0.112	7.50
7 (duplicate)	Total	6/19/18	Lehigh Site 03	35.6	0.263	18.9
10	Dissolved	6/19/18	Lehigh Site 04	39.1	0.104	18.7
10	Particulate	6/19/18	Lehigh Site 04	39.1	0.091	2.00
10	Total	6/19/18	Lehigh Site 04	39.1	0.195	20.7
14	Dissolved	6/19/18	Lehigh Site 05	44.9	0.132	13.5
14	Particulate	6/19/18	Lehigh Site 05	44.9	0.111	4.7
14	Total	6/19/18	Lehigh Site 05	44.9	0.243	18.2
14 (duplicate)	Dissolved	6/19/18	Lehigh Site 05	44.9	0.072	13.8
14 (duplicate)	Particulate	6/19/18	Lehigh Site 05	44.9	0.171	4.60
14 (duplicate)	Total	6/19/18	Lehigh Site 05	44.9	0.243	18.4

16	Dissolved	7/2/18	Lehigh Site 02	25.6	0.137	20.6
16	Particulate	7/2/18	Lehigh Site 02	25.6	0.157	5.80
16	Total	7/2/18	Lehigh Site 02	25.6	0.294	26.4
18	Dissolved	7/2/18	Lehigh Site 02	25.6	0.152	13.8
18	Particulate	7/2/18	Lehigh Site 02	25.6	1.23	13.2
18	Total	7/2/18	Lehigh Site 02	25.6	1.38	27.0
21	Dissolved	7/2/18	Lehigh Site 03	35.6	0.138	13.5
21	Particulate	7/2/18	Lehigh Site 03	35.6	0.188	2.20
21	Total	7/2/18	Lehigh Site 03	35.6	0.326	15.7
23	Dissolved	7/2/18	Lehigh Site 03	35.6	0.175	17.9
23	Particulate	7/2/18	Lehigh Site 03	35.6	0.147	1.00
23	Total	7/2/18	Lehigh Site 03	35.6	0.322	18.9
25	Dissolved	7/2/18	Lehigh Site 04	39.1	0.206	19.1
25	Particulate	7/2/18	Lehigh Site 04	39.1	0.071	3.00
25	Total	7/2/18	Lehigh Site 04	39.1	0.277	22.1
28	Dissolved	7/2/18	Lehigh Site 05	44.9	0.116	9.34
28	Particulate	7/2/18	Lehigh Site 05	44.9	0.317	8.86
28	Total	7/2/18	Lehigh Site 05	44.9	0.433	18.2
29	Dissolved	7/2/18	Lehigh Site 06	54.7	0.139	11.4
29	Particulate	7/2/18	Lehigh Site 06	54.7	0.285	2.20
29	Total	7/2/18	Lehigh Site 06	54.7	0.424	13.6
32	Dissolved	7/19/18	Lehigh Site 02	25.6	0.322	23.4
32	Particulate	7/19/18	Lehigh Site 02	25.6	0.24	-
32	Total	7/19/18	Lehigh Site 02	25.6	0.562	21.4
35	Dissolved	7/19/18	Lehigh Site 01	22.3	0.176	19.2

35	Particulate	7/19/18	Lehigh Site 01	22.3	0.312	3.20
35	Total	7/19/18	Lehigh Site 01	22.3	0.488	22.4
36	Dissolved	7/19/18	Lehigh Site 01	22.3	0.221	23.5
36	Particulate	7/19/18	Lehigh Site 01	22.3	0.246	-
36	Total	7/19/18	Lehigh Site 01	22.3	0.467	23.3
38	Dissolved	7/19/18	Lehigh Site 03	35.6	0.157	16.9
38	Particulate	7/19/18	Lehigh Site 03	35.6	0.320	11.9
38	Total	7/19/18	Lehigh Site 03	35.6	0.477	28.8
40	Dissolved	7/19/18	Lehigh Site 04	39.1	0.174	15.1
40	Particulate	7/19/18	Lehigh Site 04	39.1	0.433	4.4
40	Total	7/19/18	Lehigh Site 04	39.1	0.607	19.5
43	Dissolved	7/19/18	Lehigh Site 05	44.9	0.178	17.9
43	Particulate	7/19/18	Lehigh Site 05	44.9	0.683	40.3
43	Total	7/19/18	Lehigh Site 05	44.9	0.861	58.2

Figure 6: Data table showing the date, location, distance along the Lehigh River, and lead and zinc concentrations for the samples from the Lehigh River. The distance is a measurement of how far the site location is from Palmerton measured along the Lehigh River in kilometers, and the element concentrations are given in ppb.

The data obtained from the ICP-MS for the tributary samples, along with location data for each sample, is also shown in the table below.

Sample #	**State**	**Date**	**Location**	**Distance**	**Lead**	**Zinc**
1	Dissolved	6/19/18	Hokendauqua Site	22.6	0.088	2.33
1	Total	6/19/18	Hokendauqua Site	22.6	0.393	10.5
1	Particulate	6/19/18	Hokendauqua Site	22.6	0.305	8.17
3	Dissolved	6/19/18	Coplay Creek Site	25.2	0.0920	4.06
3	Total	6/19/18	Coplay Creek Site	25.2	0.418	5.48
3	Particulate	6/19/18	Coplay Creek Site	25.2	0.326	1.42
5	Dissolved	6/19/18	Jordan Creek Site	32.8	0.283	10.6
5	Total	6/19/18	Jordan Creek Site	32.8	0.833	9.03
5	Particulate	6/19/18	Jordan Creek Site	32.8	0.550	-
6	Dissolved	6/19/18	Little Lehigh Site	32.8	0.0800	7.10
6	Total	6/19/18	Little Lehigh Site	32.8	0.335	8.17
6	Particulate	6/19/18	Little Lehigh Site	32.8	0.255	1.07
8	Dissolved	6/19/18	Monocacy Creek Site	40.4	0.0360	3.08
8	Total	6/19/18	Monocacy Creek Site	40.4	0.151	5.26
8	Particulate	6/19/18	Monocacy Creek Site	40.4	0.115	2.18
9	Dissolved	6/19/18	Monocacy Creek Site	40.4	0.0640	7.00
9	Total	6/19/18	Monocacy Creek Site	40.4	0.124	6.20
9	Particulate	6/19/18	Monocacy Creek Site	40.4	0.0600	-
12	Dissolved	6/19/18	Saucon Creek Site	43.5	0.0680	12.0
12	Total	6/19/18	Saucon Creek Site	43.5	0.215	11.5
12	Particulate	6/19/18	Saucon Creek Site	43.5	0.147	-
13	Dissolved	6/19/18	East Branch Saucon Site	43.5	0.108	11.6
13	Total	6/19/18	East Branch Saucon Site	43.5	0.0880	2.93
13	Particulate	6/19/18	East Branch Saucon Site	43.5	-	-

15	Dissolved	7/2/18	Hokendauqua Site	22.6	0.130	10.7
15	Total	7/2/18	Hokendauqua Site	22.6	0.212	6.06
15	Particulate	7/2/18	Hokendauqua Site	22.6	0.0820	-
17	Dissolved	7/2/18	Coplay Creek Site	25.2	0.0920	4.15
17	Total	7/2/18	Coplay Creek Site	25.2	0.384	4.53
17	Particulate	7/2/18	Coplay Creek Site	25.2	0.292	0.38
19	Dissolved	7/2/18	Jordan Creek Site	32.8	0.0950	3.83
19	Total	7/2/18	Jordan Creek Site	32.8	0.729	3.70
19	Particulate	7/2/18	Jordan Creek Site	32.8	0.634	-
20	Dissolved	7/2/18	Little Lehigh Site	32.8	0.0980	7.20
20	Total	7/2/18	Little Lehigh Site	32.8	0.176	0.633
20	Particulate	7/2/18	Little Lehigh Site	32.8	0.0780	-
24	Dissolved	7/2/18	Monocacy Creek Site	40.4	0.0320	2.53
24	Total	7/2/18	Monocacy Creek Site	40.4	0.236	2.70
24	Particulate	7/2/18	Monocacy Creek Site	40.4	0.204	0.170
26	Dissolved	7/2/18	East Branch Saucon Site	43.5	0.0170	6.12
26	Total	7/2/18	East Branch Saucon Site	43.5	0.121	6.45
26	Particulate	7/2/18	East Branch Saucon Site	43.5	0.104	0.330
27	Dissolved	7/2/18	Saucon Creek Site	43.5	0.0410	6.67
27	Total	7/2/18	Saucon Creek Site	43.5	0.215	6.90
27	Particulate	7/2/18	Saucon Creek Site	43.5	0.174	0.230
30	Dissolved	7/2/18	Jordan Creek Site	32.8	0.139	9.48
30	Total	7/19/18	Jordan Creek Site	32.8	0.417	9.65
30	Particulate	7/19/18	Jordan Creek Site	32.8	0.278	0.170
31	Dissolved	7/19/18	Little Lehigh Site	32.8	0.152	5.00

31	Total	7/19/18	Little Lehigh Site	32.8	0.195	5.03
31	Particulate	7/19/18	Little Lehigh Site	32.8	0.0430	0.03
33	Dissolved	7/19/18	Coplay Creek Site	25.2	0.0816	8.55
33	Total	7/19/18	Coplay Creek Site	25.2	0.207	5.00
33	Particulate	7/19/18	Coplay Creek Site	25.2	0.125	-
34	Dissolved	7/19/18	Hokendauqua Site	22.6	0.101	8.30
34	Total	7/19/18	Hokendauqua Site	22.6	0.258	11.4
34	Particulate	7/19/18	Hokendauqua Site	22.6	0.157	3.10
39	Dissolved	7/19/18	Monocacy Creek Site	40.4	0.151	9.40
39	Total	7/19/18	Monocacy Creek Site	40.4	0.310	11.20
39	Particulate	7/19/18	Monocacy Creek Site	40.4	0.159	1.80
41	Dissolved	7/19/18	Saucon Creek Site	43.5	0.0861	11.6
41	Total	7/19/18	Saucon Creek Site	43.5	0.216	9.61
41	Particulate	7/19/18	Saucon Creek Site	43.5	0.130	-
42	Dissolved	7/19/18	East Branch Saucon Site	43.5	0.0443	10.1
42	Total	7/19/18	East Branch Saucon Site	43.5	0.306	5.98
42	Particulate	7/19/18	East Branch Saucon Site	43.5	0.262	-

Figure 7: Data table showing the date, location, distance along the Lehigh River, and lead and zinc concentrations for the samples from the Lehigh River's tributaries. The distance is a measurement of how far from Palmerton the location where the tributary meets the Lehigh River is, measured along the Lehigh River in kilometers, and the element concentrations are given in ppb.

This data from the ICP-MS was analyzed in excel and used to determine that a majority of the samples had more lead travelling in the particulate form than the dissolved form. However, both forms are still important to analyze.

The values of the lead concentrations from the Lehigh River and its tributaries were first looked at in relation to the EPA's action level of 15 ppb (*United States Environmental Protection Agency*, n.d. b), as shown below:

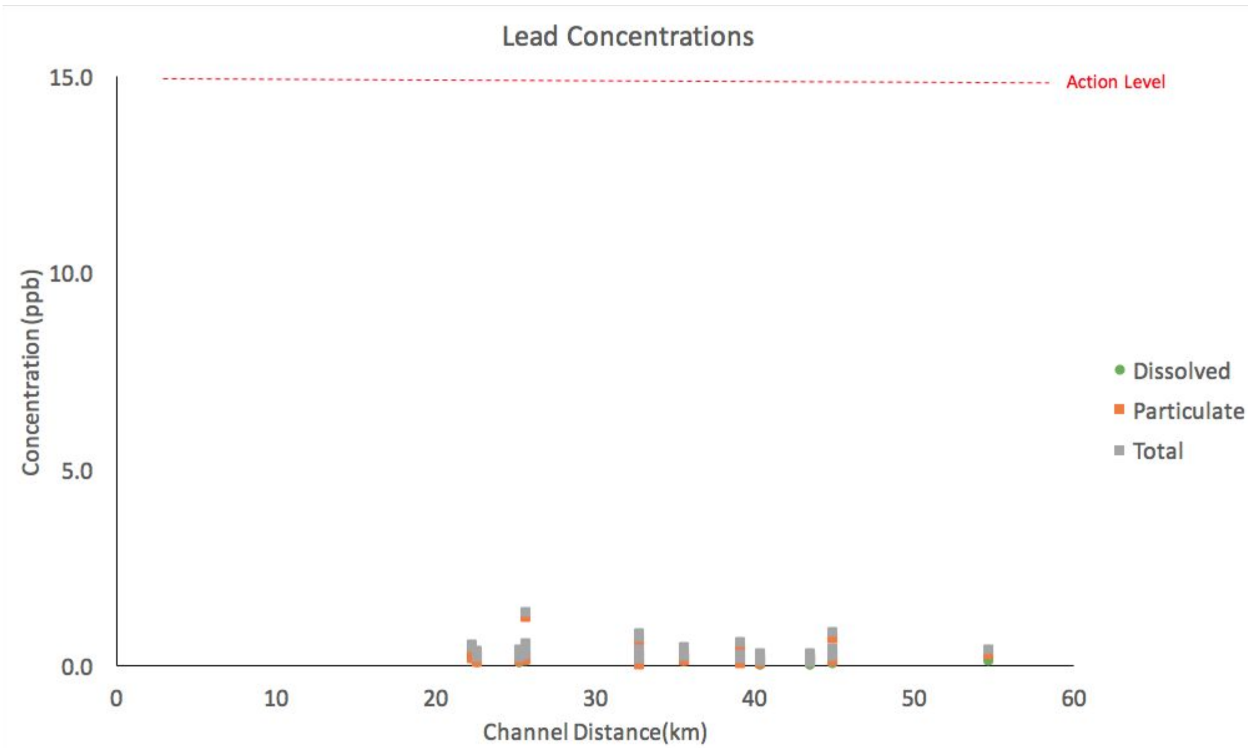


Figure 8: Lead concentrations from the Lehigh River and its tributaries. None of the concentrations reach the EPA's action level of 15 ppb (United States Environmental Protection Agency, n.d. b).

The lead concentrations for the Lehigh River mainstem samples were also plotted against their distance to the respective sample site along the Lehigh River, which is referred to as the "channel distance." Palmerton was set as the 0 point for the channel distance. This is shown in the figure below:

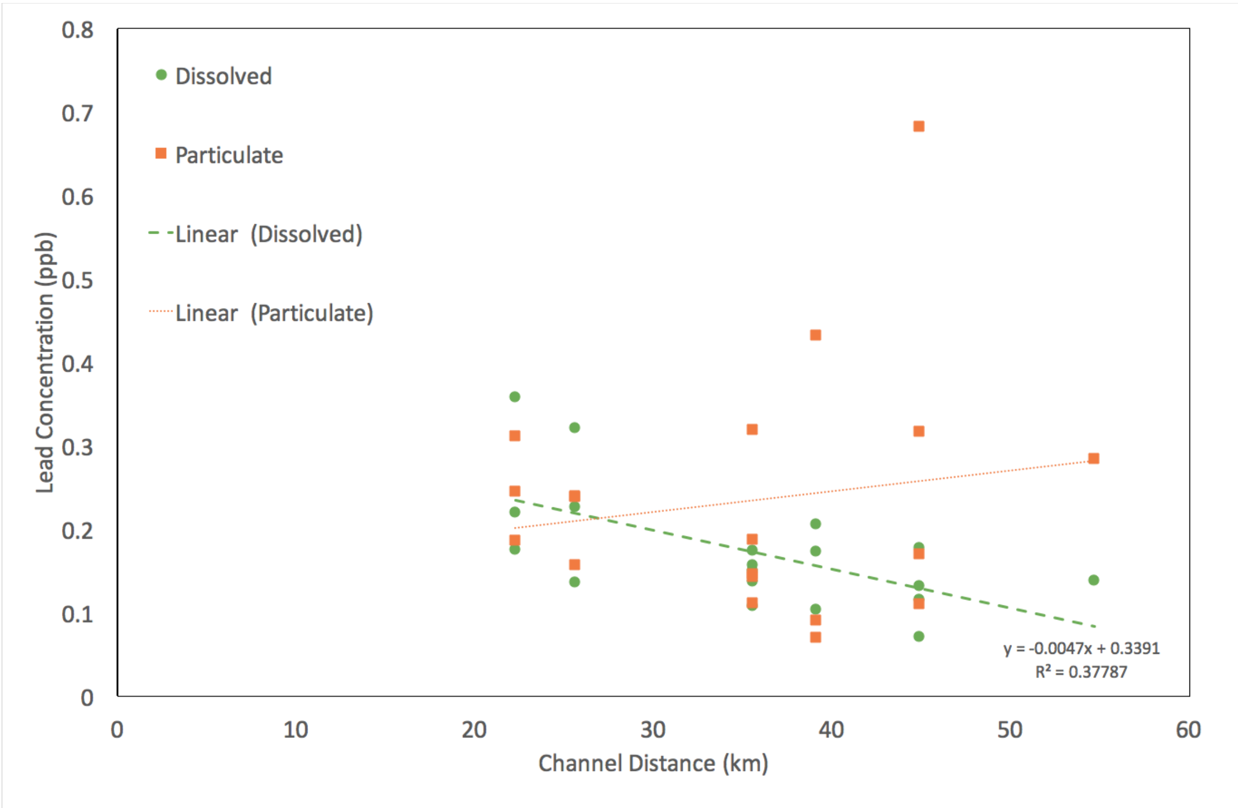
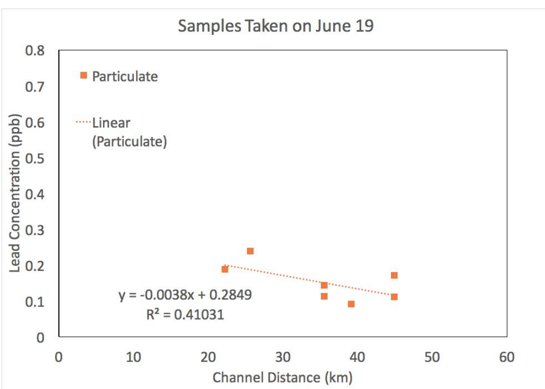


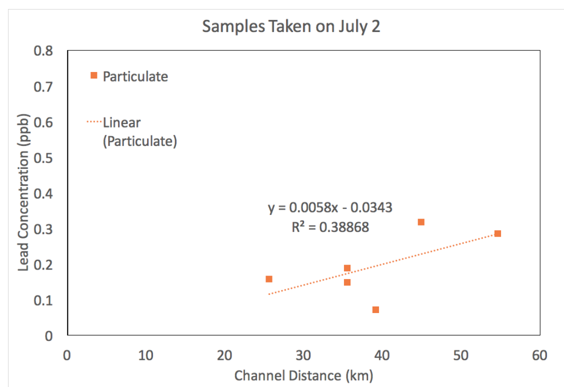
Figure 9: Lead concentrations for the samples taken from the Lehigh River plotted against the sample site's channel distance.

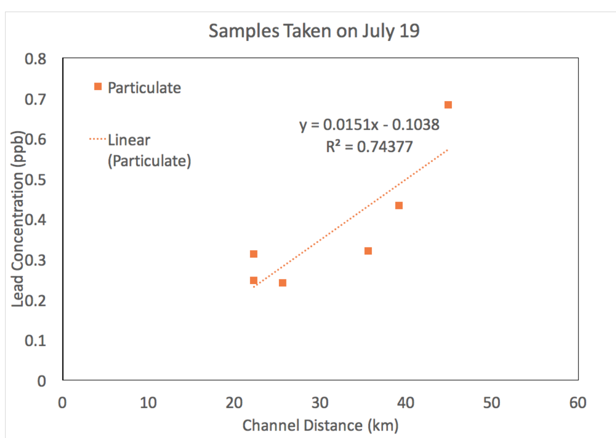
For this graph, sample 018, which was taken at Lehigh Site 02, was not included in the graph and data calculations, as it had a much higher elemental concentration than the other sites and it is preferable to look at the overall pattern of all the sites rather than just one. However, it was included in the toxicity calculations.

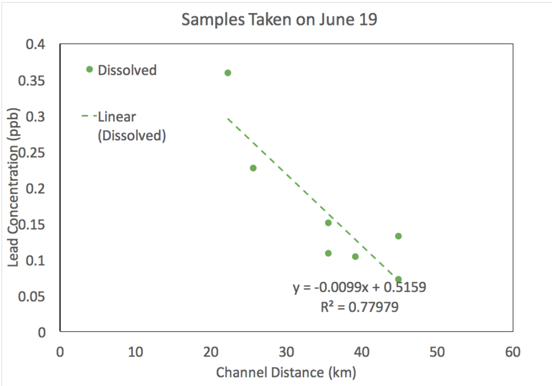
While the particulate lead concentrations do not show much correlation with the distance from Palmerton, the dissolved lead concentrations decrease as the distance from Palmerton increases. The particulate lead concentrations, when plotted against the distance from Palmerton, have a shallow positive slope, a very weak R^2 value, and a p-value of 0.5088. The dissolved lead concentrations have a steeper negative slope, a moderate R^2 value, and a p-value of 0.005098. The particulate concentration data had a p-value greater than 0.05, and therefore fails to reject the null hypothesis. The particulate lead and channel distance dataset is not statistically significant. However, the dissolved concentration data had a p-value less than 0.05, and therefore the null hypothesis is rejected. The dissolved lead and channel distance dataset is statistically significant.

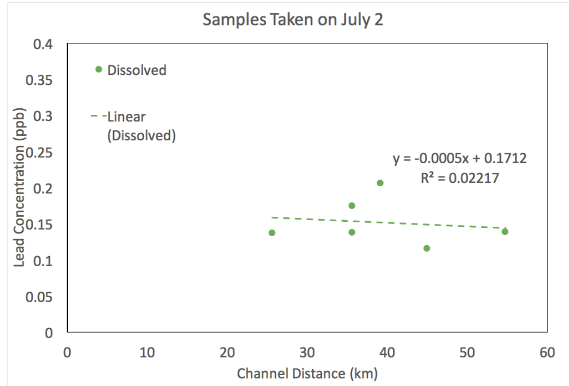
The combined data for all three sites can also be broken down by each round of sampling. This is important to look at because the lead concentrations can vary under different sampling conditions. The broken down distributions of lead concentrations are shown below:











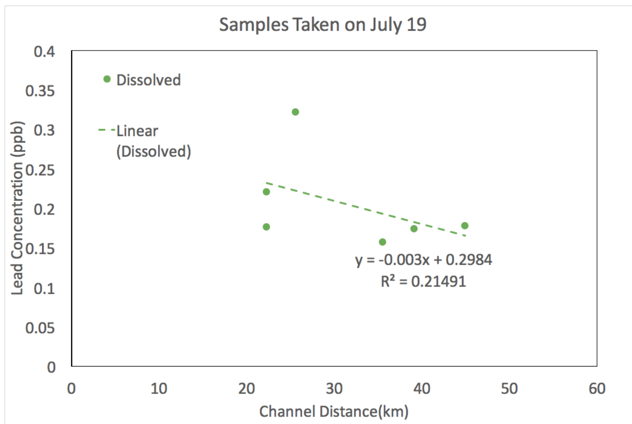


Figure 10: The particulate and dissolved lead concentrations for each round of sampling graphed against the sample site's channel distance.

For each individual round of sampling, the same trends that were seen in the overall graph are present, except for the particulate lead values for the first round of sampling. Rather than increasing with distance from Palmerton, these values are decreasing. However, the dissolved concentrations of lead still decrease for the first round of sampling. For the other two rounds of sampling, the particulate concentrations increase with distance, and the dissolved concentrations decrease with distance. It should also be noted that the particulate concentrations of lead were higher on the July 19th sampling date than the other two dates.

The correlation of lead concentrations with zinc concentrations for the samples taken along the Lehigh River was also determined from the dataset and graphed below. Sample 018 was also not included in this graph.

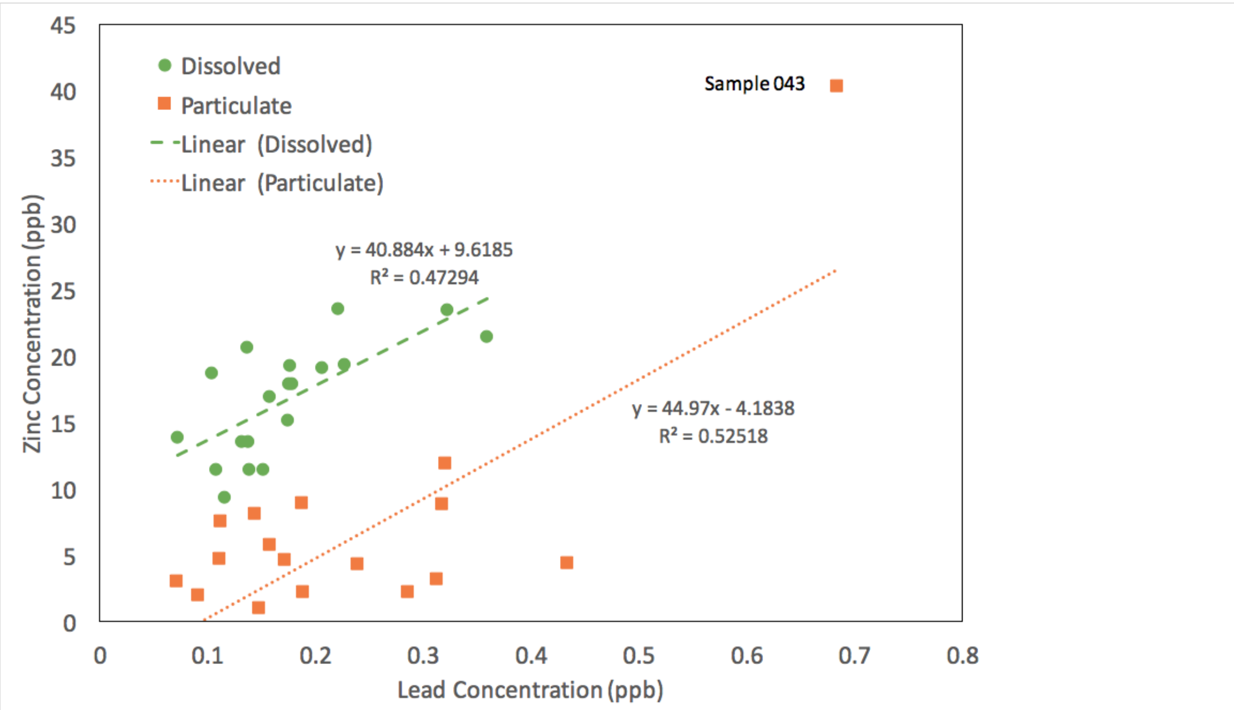


Figure 11: Correlation of dissolved and particulate zinc and lead concentrations. The particulate concentration of sample 043, which was taken at Lehigh Site 05 on July 19, is labeled because it has values greater than the rest of the data.

Unfortunately this data does not have a lot of replication due to limits on sampling, but trends can still be found in the available data. A positive correlation between zinc and lead concentrations is present for both the dissolved and particulate concentrations. The dissolved concentrations have a steep positive slope, a strong R^2 value, and a p-value of 0.00113763. The particulate concentrations also have a positive slope, a strong R^2 value, and a p-value of 0.00044859. The dissolved lead and zinc concentrations have a p-value which is less than the significance level of 0.05 and therefore the null hypothesis is rejected and the data is statistically significant. The particulate lead and zinc concentrations have a p-value which is less than the significance level of 0.05 and therefore the null hypothesis is rejected and this data is also statistically significant.

The concentrations of lead and zinc can also be looked at in respect to channel distance, which is shown below:

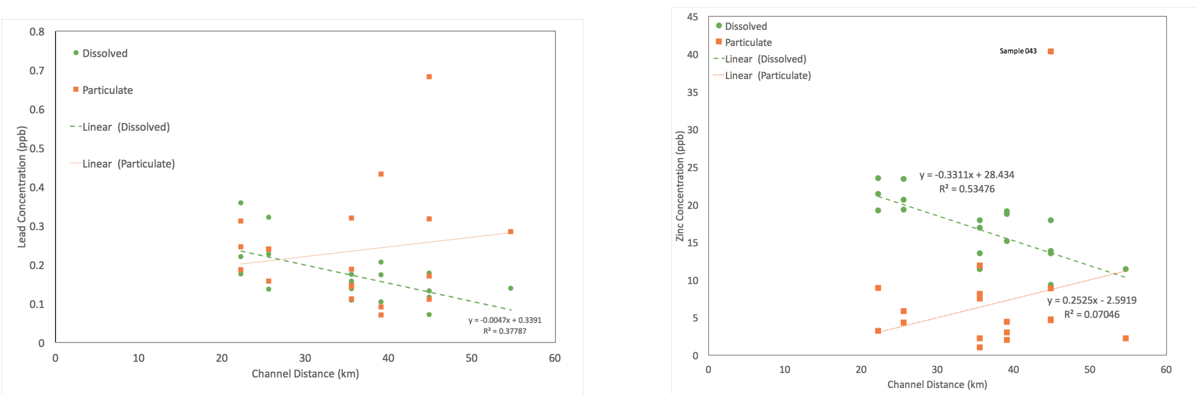


Figure 12: Lead concentrations (left) and zinc concentrations (right) with respect to channel distance for the Lehigh River samples.

The lead and zinc concentrations show similar patterns. For both, the particulate concentrations increase slightly and the dissolved concentrations decrease with a higher correlation as the channel distance increases. This indicates that they are travelling together.

The correlations between lead and aluminum, manganese, and iron were also plotted because they had the highest R^2 values for the overall dataset. The lead and aluminum concentrations for the Lehigh River are shown in the table below.

Sample Number	State	Lead	Zinc	Aluminum	Manganese	Iron
2	Dissolved	0.359	21.4	60.6	22.1	68.9
2	Particulate	0.187	8.90	20.2	6.50	50.1
2	Total	0.546	30.3	80.8	28.6	119
4	Dissolved	0.227	19.3	51.9	17.8	61.4
4	Particulate	0.239	4.30	23.8	6.90	50.6
4	Total	0.466	23.6	75.7	24.7	112
7	Dissolved	0.108	11.4	65.0	14.3	70.9
7	Particulate	0.143	8.10	18.7	6.20	40.1
7	Total	0.251	19.5	83.7	20.5	111
7 (duplicate)	Dissolved	0.151	11.4	63.6	14.2	71.1
7 (duplicate)	Particulate	0.112	7.50	11.8	5.30	44.9
7 (duplicate)	Total	0.263	18.9	75.4	19.5	116
10	Dissolved	0.104	18.7	80.3	17.2	85.1
10	Particulate	0.0910	2.00	17.1	7.90	41.9
10	Total	0.195	20.7	97.4	25.1	127
14	Dissolved	0.132	13.5	72.7	12.6	69.8
14	Particulate	0.111	4.70	15.1	7.60	57.2
14	Total	0.243	18.2	87.8	20.2	127
14 (duplicate)	Dissolved	0.072	13.8	75.1	12.9	73.9
14 (duplicate)	Particulate	0.171	4.60	13.8	7.40	54.1
14 (duplicate)	Total	0.243	18.4	88.9	20.3	128
16	Dissolved	0.137	20.6	72.4	20.1	75.5
16	Particulate	0.157	5.80	28.6	17.5	47.5

16	Total	0.294	26.4	101	37.6	123
18	Dissolved	0.152	13.8	62.0	23.4	56.5
18	Particulate	1.23	13.2	134	43.7	191
18	Total	1.38	27.0	196	67.1	247
21	Dissolved	0.138	13.5	47.6	19.3	55.1
21	Particulate	0.188	2.20	19.7	6.50	30.6
21	Total	0.326	15.7	67.3	25.8	85.7
23	Dissolved	0.175	17.9	46.2	19.4	52.7
23	Particulate	0.147	1.00	20.2	6.90	34.9
23	Total	0.322	18.9	66.4	26.3	87.6
25	Dissolved	0.206	19.1	53.6	18.3	48.1
25	Particulate	0.071	3.00	16.8	6.90	32.5
25	Total	0.277	22.1	70.4	25.2	80.6
28	Dissolved	0.116	9.34	48.6	13.3	37.7
28	Particulate	0.317	8.86	29.5	12.1	46.9
28	Total	0.433	18.2	78.1	25.4	84.6
29	Dissolved	0.139	11.4	38.1	23.5	41.8
29	Particulate	0.285	2.20	26.1	9.20	50.4
29	Total	0.424	13.6	64.2	32.7	92.2
32	Dissolved	0.322	23.4	67.2	21.2	72.0
32	Particulate	0.240	-	53.8	24.9	154
32	Total	0.562	21.4	121	46.1	226
35	Dissolved	0.176	19.2	85.2	20.8	83.0
35	Particulate	0.312	3.20	69.8	23.1	137
35	Total	0.488	22.4	155	43.9	220

36	Dissolved	0.221	23.5	87.1	22.8	92.0
36	Particulate	0.246	-	68.9	21.8	107
36	Total	0.467	23.3	156	44.6	199
38	Dissolved	0.157	16.9	55.5	14.0	69.0
38	Particulate	0.320	11.9	54.5	11.2	120
38	Total	0.477	28.8	110	25.2	189
40	Dissolved	0.174	15.1	56.7	21.0	73.0
40	Particulate	0.433	4.40	56.3	17.2	174
40	Total	0.607	19.5	113	38.2	247
43	Dissolved	0.178	17.9	50.4	22.3	71.0
43	Particulate	0.683	40.3	114	18.9	223
43	Total	0.861	58.2	164	41.2	294

Figure 13: Table showing the concentrations of lead, zinc, aluminum, manganese, and iron for the Lehigh River samples. The element concentrations are given in ppb.

The dissolved and particulate concentrations of the elements were then graphed in relation to the lead concentrations, as is shown below:

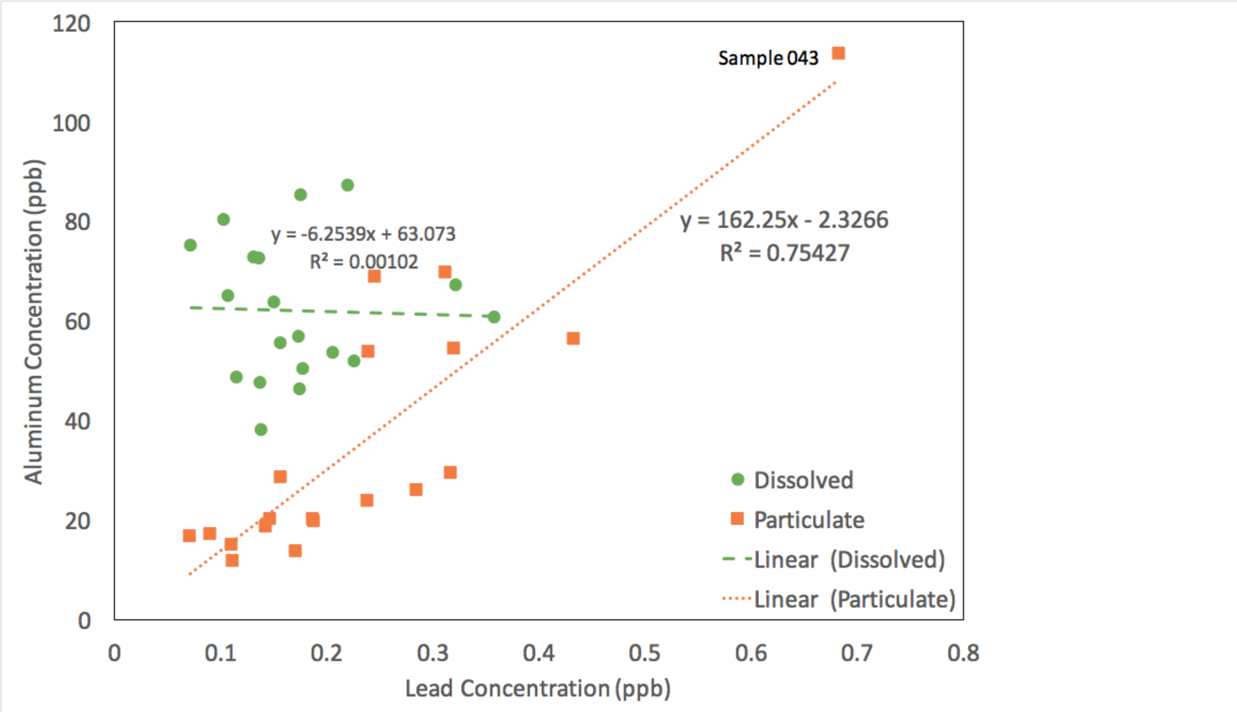


Figure 14: Correlation of dissolved and particulate aluminum and lead concentrations. The particulate concentration of sample 043, which was taken at Lehigh Site 05 on July 19, is labeled because it has values greater than the rest of the data.

The dissolved aluminum and lead concentrations have a shallow negative slope, a weak R^2 value, and a p-value of 0.897. The particulate concentrations have a steep positive slope, a strong R^2 value, and a p-value of 1.423 $x10^{-6}$. The dissolved aluminum and lead concentrations have a p-value which is greater than the significance level of 0.5, and therefore fails to reject the null hypothesis. The data is not statistically significant. However, the particulate concentrations have a p-value which is less than the significance level of 0.5, and therefore the null hypothesis is rejected and the data is statistically significant.

The correlations between dissolved and particulate manganese and lead were also plotted in the figure below.

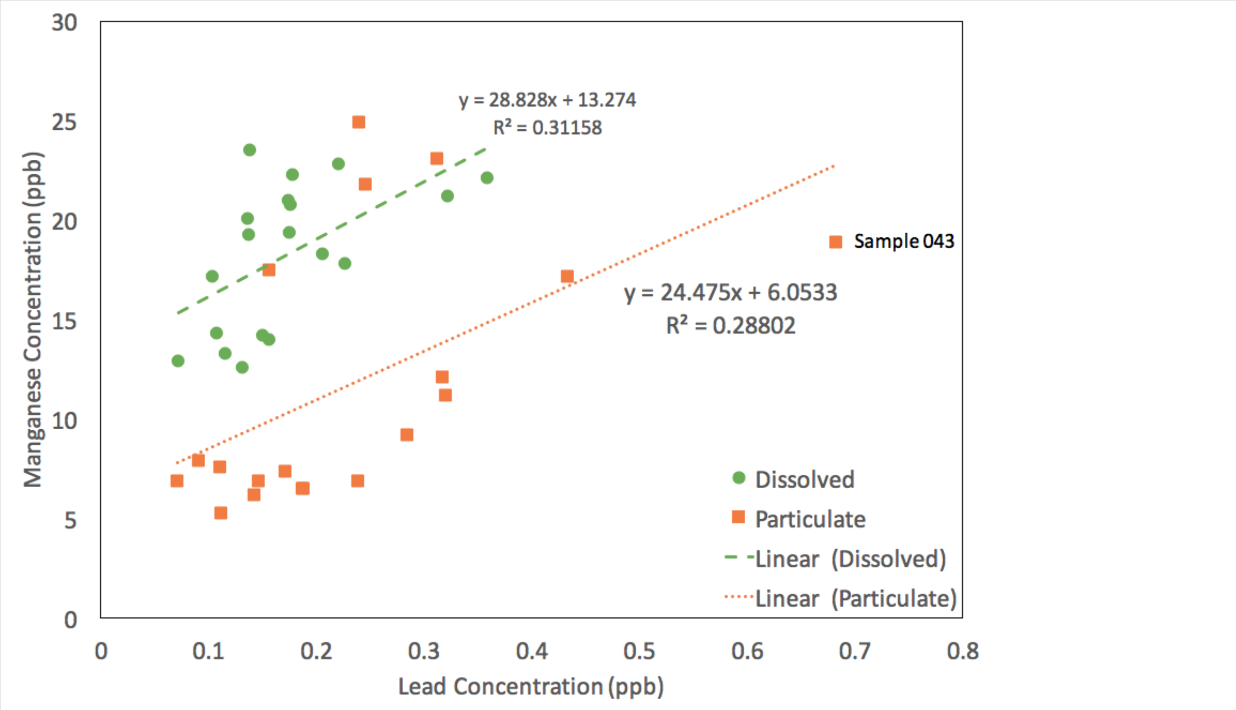


Figure 15: Correlation of dissolved and particulate manganese and lead concentrations. The particulate concentration of sample 043, which was taken at Lehigh Site 05 on July 19, is labeled because it has values greater than the rest of the data.

For manganese and lead, the dissolved and particulate concentrations had more similar trends. The dissolved concentrations have a positive best fit slope, a moderate R^2 value, and a p-value of 0.0130. The particulate concentrations have a positive best fit slope, a weak R^2 value, and a p-value of 0.0178. Both p-values for dissolved and particulate forms are less than the significance level of 0.05, and therefore the null hypothesis is rejected and the data is statistically significant.

The correlations between dissolved and particulate iron were also examined. These are shown in the graph below.

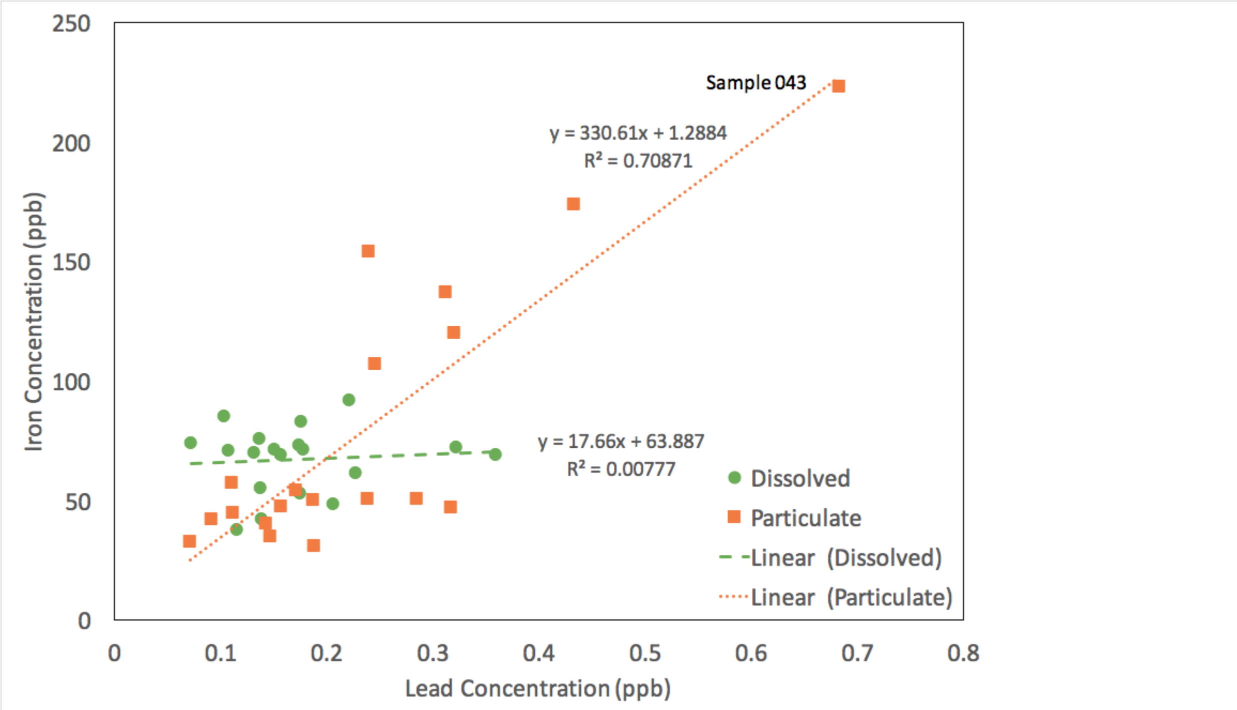


Figure 16: Correlation of dissolved and particulate iron and lead concentrations. The particulate concentration of sample 043, which was taken at Lehigh Site 05 on July 19, is labeled because it has values greater than the rest of the data.

While the dissolved concentrations do not have a steep best fit line slope nor strong R^2 value, the particulate concentrations do. The dissolved iron and lead concentrations were calculated to have a p-value of 0.7198, which is greater than the significance level of 0.05, and therefore fails to reject the null hypothesis. The data is not statistically significant. However, the particulate iron and lead concentrations have a p-value of 6.208×10^{-6}, which is less than the significance level of 0.05, and therefore the null hypothesis is rejected and the data is statistically significant.

The levels of lead, zinc, aluminum, manganese, and iron were also compared to the values from the tributaries leading into the Lehigh River. This was accomplished using flux diagrams (*Blake*, 2010), which show the element concentrations in relation to the discharge of where they are sampled from. The top of each diagram represents the site furthest upstream (Site 1), while the bottom represents the sites furthest downstream (Sites 5 and 6) along the Lehigh River. The flux diagrams were created using the average flux values for the sites and are pictured below:

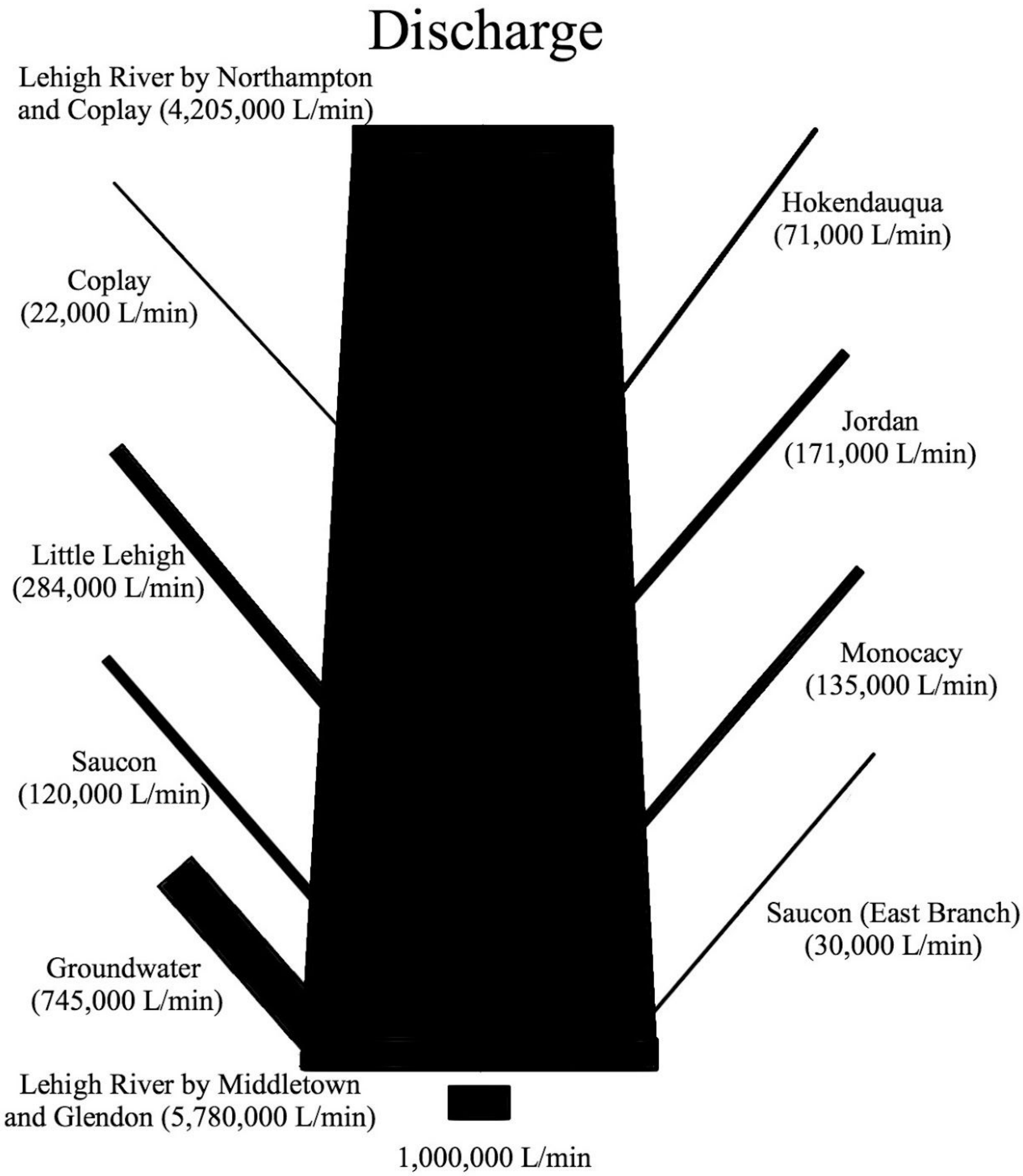


Figure 17: Diagram showing the approximate discharge of the Lehigh River and its tributaries. Site 1, which is represented by the top of the diagram, was used with sites 5 and 6, which is represented by the bottom, to approximate the discharge of the Lehigh River.

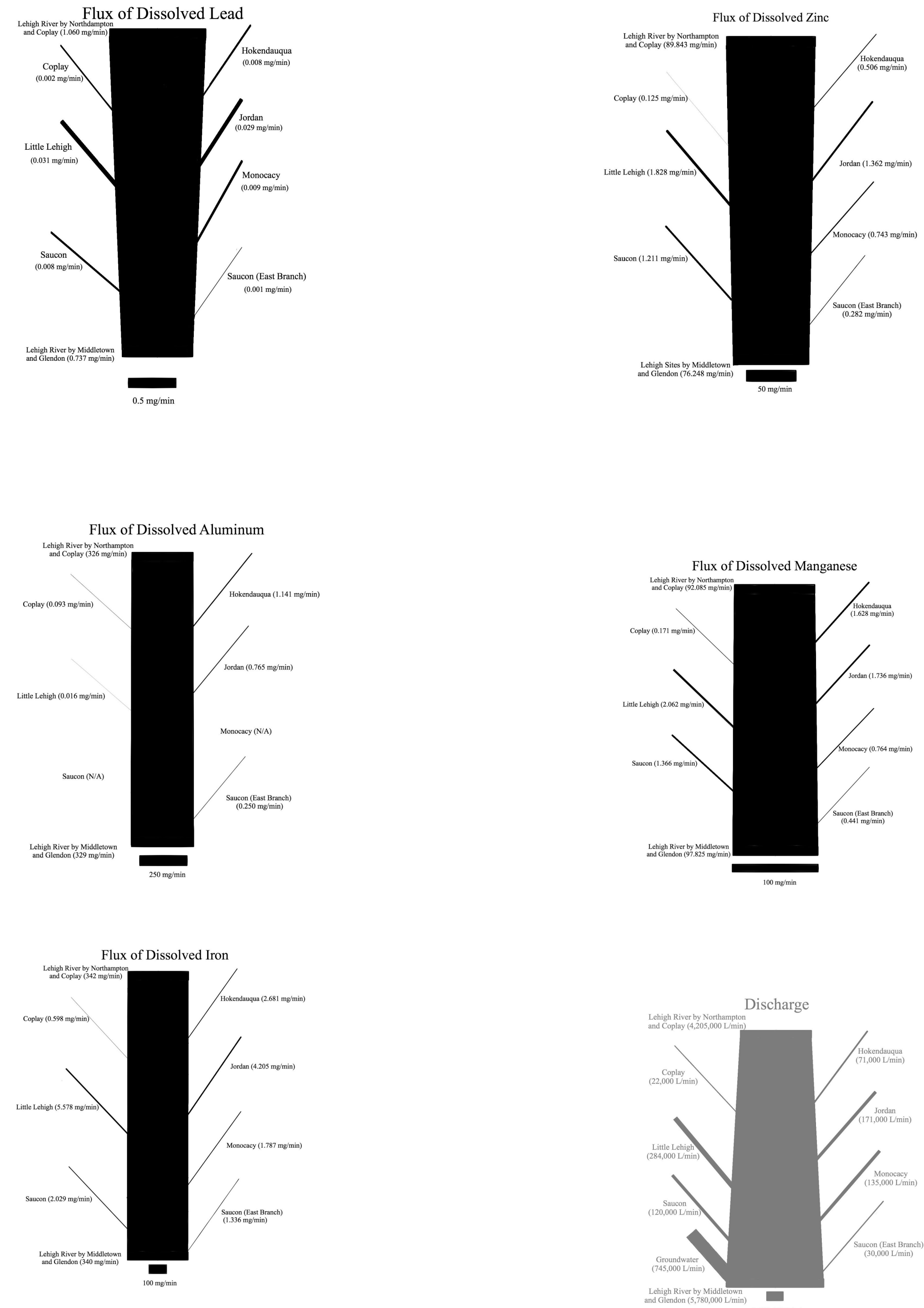


Figure 18: The flux values for dissolved lead, zinc, aluminum, manganese, and iron are shown. Discharge is also included for comparison.

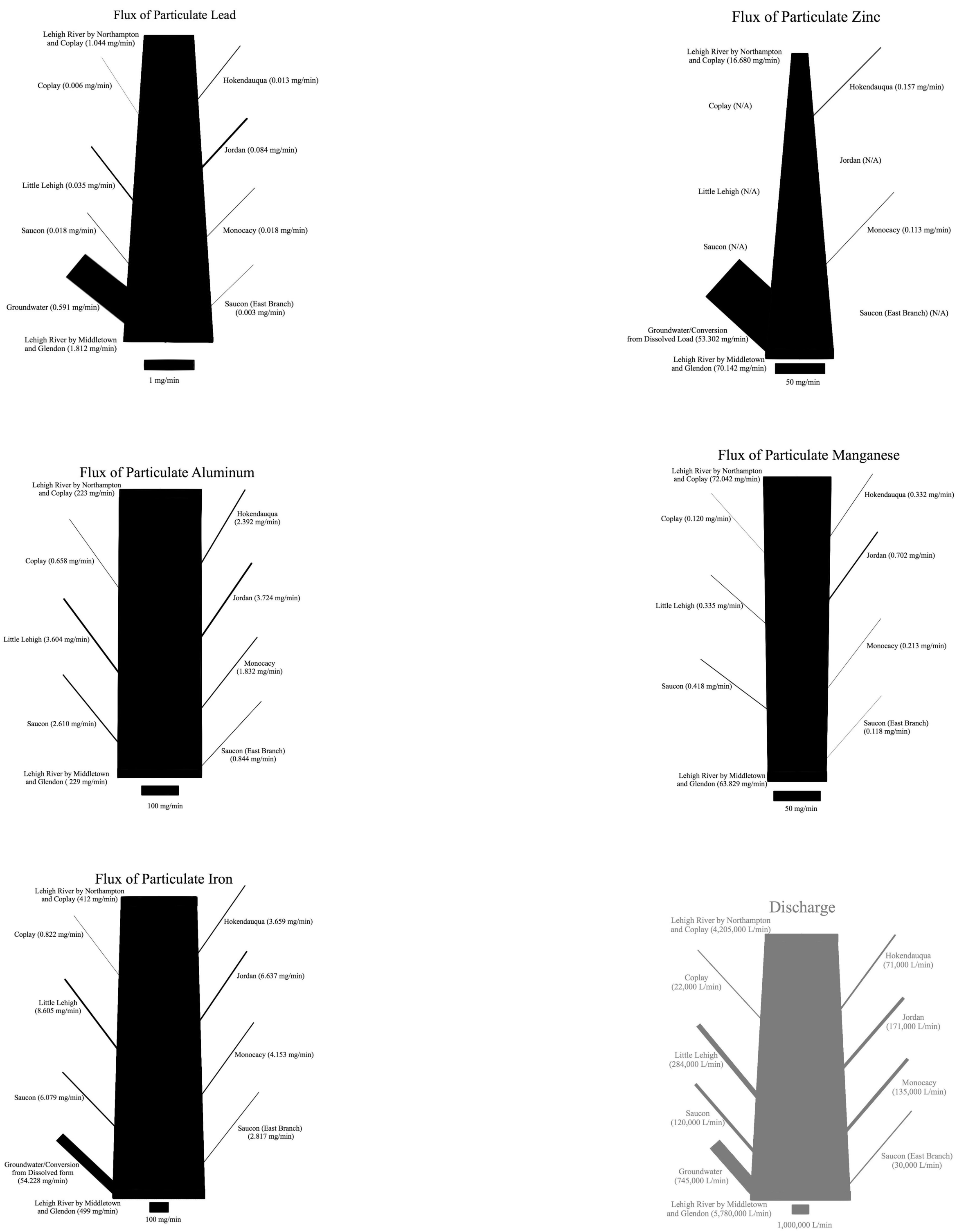


Figure 19: The flux values for particulate lead, zinc, aluminum, manganese, and iron are shown. Discharge is also included for comparison.

The toxicity levels of the lead were also calculated for the samples. The data used to calculate the toxicity levels for the sites along the Lehigh River is summarized in the table below.

Sample #	**State**	**Lead**	**Calcium**	**Magnesium**	**Hardness**	**% measured vs criteria chronic**	**% measured vs criteria acute**
2	Dissolved	0.359	10000	4050	41.6	37.50%	1.46%
2	Particulate	0.187	-	30.0	41.2	19.70%	0.77%
2	Total	0.546	9780	4080	41.2	57.70%	2.25%
4	Dissolved	0.227	15700	6400	65.5	14.30%	0.56%
4	Particulate	0.239	400	180	67.2	14.70%	0.57%
4	Total	0.466	16100	6580	67.2	28.60%	1.12%
7	Dissolved	0.108	21100	10500	95.8	4.50%	0.18%
7	Particulate	0.143	400	200	97.6	5.83%	0.23%
7	Total	0.251	21500	10700	97.6	10.20%	0.40%
7 (duplicate)	Dissolved	0.151	20700	10500	94.8	6.36%	0.25%
7 (duplicate)	Particulate	0.112	-	-	93.0	4.82%	0.19%
7 (duplicate)	Total	0.263	20300	10300	93.0	11.30%	0.44%
10	Dissolved	0.104	18300	9220	83.6	5.03%	0.20%
10	Particulate	0.091	200	120	84.5	4.35%	0.17%
10	Total	0.195	18500	9340	84.5	9.31%	0.36%
14	Dissolved	0.132	21200	11400	99.7	5.26%	0.21%
14	Particulate	0.111	800	300	103	4.27%	0.17%
14	Total	0.243	22000	11700	103	9.35%	0.36%
14 (duplicate)	Dissolved	0.072	21400	11700	101	2.83%	0.11%
14 (duplicate)	Particulate	0.171	700	-	103	6.58%	0.26%

14 (duplicate)	Total	0.243	22100	11600	103	9.35%	0.36%
16	Dissolved	0.137	10100	4180	42.4	14.00%	0.55%
16	Particulate	0.157	-	-	41.9	16.30%	0.63%
16	Total	0.294	10000	4110	41.9	30.50%	1.19%
18	Dissolved	0.152	15900	6170	65.0	9.68%	0.38%
18	Particulate	1.23	100	-	65.1	78.10%	3.04%
18	Total	1.38	16000	6120	65.1	87.80%	3.42%
21	Dissolved	0.138	20300	9840	91.1	6.07%	0.24%
21	Particulate	0.188	100	0	91.3	8.25%	0.32%
21	Total	0.326	20400	9840	91.3	14.30%	0.56%
23	Dissolved	0.175	20100	9900	90.8	7.73%	0.30%
23	Particulate	0.147	-	10	90.4	6.52%	0.25%
23	Total	0.322	19900	9910	90.4	14.30%	0.56%
25	Dissolved	0.206	18500	9120	83.6	9.95%	0.39%
25	Particulate	0.071	600	310	86.4	3.31%	0.13%
25	Total	0.277	19100	9430	86.4	12.90%	0.50%
28	Dissolved	0.116	21300	11000	98.4	4.69%	0.18%
28	Particulate	0.317	-	0	98.1	12.90%	0.50%
28	Total	0.433	21200	11000	98.1	17.60%	0.69%
29	Dissolved	0.139	21800	11400	101	5.46%	0.21%
29	Particulate	0.285	-	-	100	11.30%	0.44%
29	Total	0.424	21700	11200	100	16.80%	0.66%
32	Dissolved	0.322	17800	5820	68.4	19.40%	0.76%
32	Particulate	0.24	60.0	40.0	68.7	14.40%	0.56%
32	Total	0.562	17900	5860	68.7	33.70%	1.31%

35	Dissolved	0.176	10700	3440	40.8	18.80%	0.73%
35	Particulate	0.312	190	70.0	41.5	32.70%	1.27%
35	Total	0.488	10900	3510	41.5	51.10%	1.99%
36	Dissolved	0.221	11000	3520	41.8	23.00%	0.90%
36	Particulate	0.246	-	-	40.6	26.40%	1.03%
36	Total	0.467	10600	3420	40.6	50.10%	1.95%
38	Dissolved	0.157	22100	8430	89.9	7.01%	0.27%
38	Particulate	0.320	-	-	88.2	14.60%	0.57%
38	Total	0.477	21700	8300	88.2	21.70%	0.85%
40	Dissolved	0.174	18300	6600	72.7	9.80%	0.38%
40	Particulate	0.433	310	140	74.1	23.90%	0.93%
40	Total	0.607	18600	6740	74.1	33.50%	1.30%
43	Dissolved	0.178	22800	8650	92.4	7.71%	0.30%
43	Particulate	0.683	1690	1110	101	26.80%	1.05%
43	Total	0.861	24500	9760	101	33.80%	1.32%

Figure 20: Table showing the lead, calcium, and magnesium concentrations with the calculated hardness and percentage of toxicity for both chronic and acute toxicity criterias of samples taken from the Lehigh River. The element concentrations are given in ppb, and the hardness is in mg/L.

The data was also summarized in a graph for the chronic toxicity criteria. The values of acute toxicity are much less than the chronic values and are not dangerous, so they were not graphed. The graph for the chronic toxicity data is shown below.

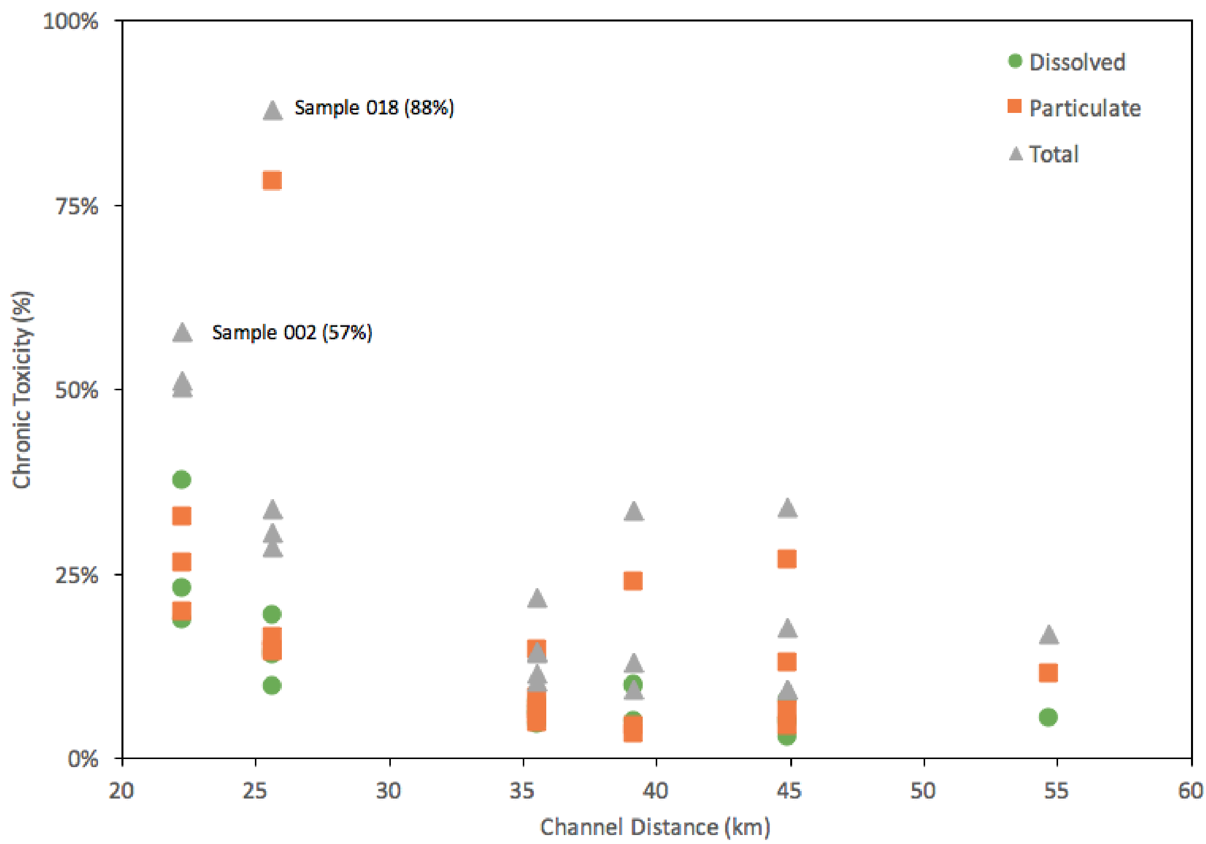


Figure 21: Dissolved, particulate, and total lead toxicity values plotted against the channel distance for each sample taken from the Lehigh River. The labeled samples are the ones with the highest chronic toxicity for their total lead concentrations. Sample 002 is located by Northampton and Coplay, and Sample 018 is located by Whitehall.

For this dataset, the total values were plotted along with the dissolved and particulate concentrations because the total amount of lead will be what affects organisms if it crosses the toxicity threshold, which is set at 100% chronic toxicity. However, none of the lead concentrations cross this threshold. The closest any of them come to the total lead concentration is sample 018 and 002, which have a chronic toxicity percentage of 88% and 57% respectively.

The chronic toxicity percentages appear to be decreasing as one travels further from the Lehigh River. However, the calcium concentration also increases as a result of the bedrock formations, as is shown in the figure below:

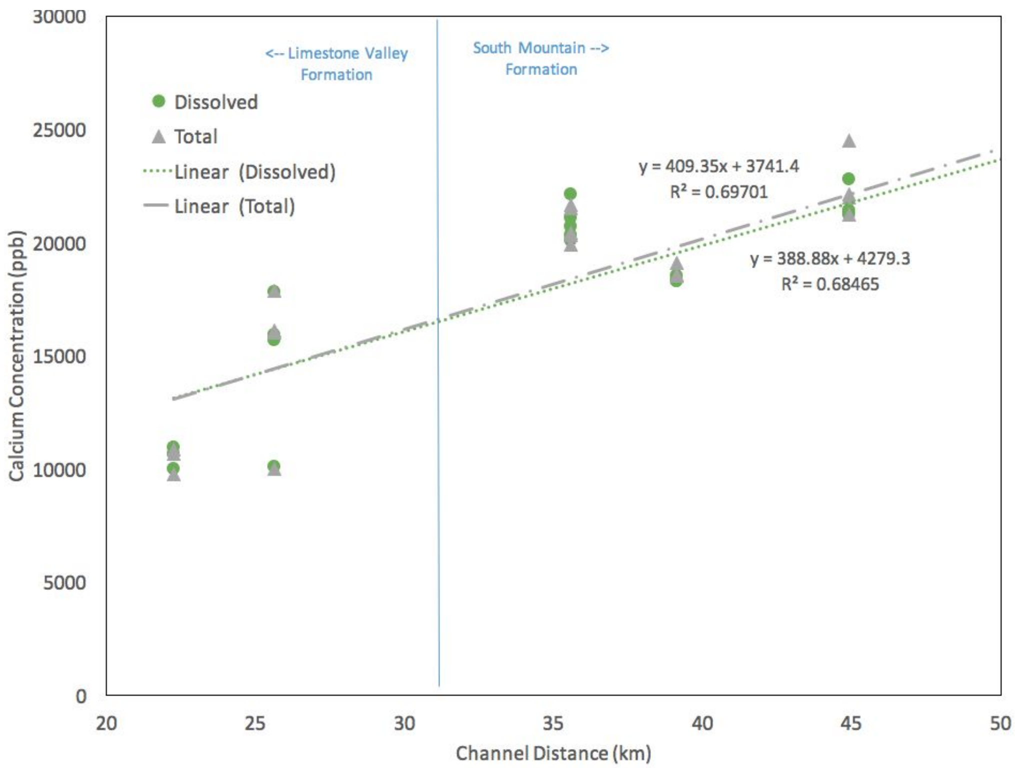


*Figure 22: The dissolved and total calcium concentrations increase further downstream, which causes an increase in hardness. This calcium likely comes from the Limestone Valley Formation bedrock (*Enviro Sci Inquiry *2011*)*. The particulate calcium concentrations were not graphed, as they had non-measurable values because calcium does not travel much in the particulate form.*

The toxicity levels for the sampled tributaries were also calculated and are summarized in the table below:

Sample #	State	Lead	Calcium	Magnesium	Hardness	% measured vs criteria chronic	% measured vs criteria acute
1	Dissolved	0.088	26300	7110	94.9	3.70%	0.14%
1	Total	0.393	26000	6960	93.5	16.80%	0.66%
1	particulate	0.305	-	-	93.5	13.00%	0.51%
3	Dissolved	0.0920	66700	21200	254	1.35%	0.05%
3	total	0.418	68100	21800	260	5.97%	0.23%
3	particulate	0.326	1400	600	260	4.66%	0.18%
5	Dissolved	0.283	43700	18700	186	5.76%	0.23%
5	total	0.833	44600	18900	189	16.70%	0.65%
5	particulate	0.550	900	200	189	11.00%	0.43%
6	Dissolved	0.0800	48200	27100	232	1.29%	0.05%
6	total	0.335	48400	27400	233	5.37%	0.21%
6	particulate	0.255	200	300	233	4.09%	0.16%
8	Dissolved	0.0360	64900	32200	294	0.45%	0.02%
8	total	0.151	66400	32800	300	1.86%	0.07%
8	particulate	0.115	1500	600	300	1.41%	0.06%
9	Dissolved	0.0640	66200	32800	300	0.79%	0.03%
9	total	0.124	65800	32900	299	1.53%	0.06%
9	particulate	0.0600	-	100	299	0.74%	0.03%
12	Dissolved	0.0680	45500	26000	220	1.16%	0.05%
12	total	0.215	45800	25900	221	3.65%	0.14%
12	particulate	0.147	300	-	221	2.49%	0.10%
13	Dissolved	0.108	50000	21100	212	1.91%	0.07%
13	total	0.0880	48700	20600	206	1.61%	0.06%

13	particulate	-	-	-	206	-	-
15	Dissolved	0.130	33100	7760	115	4.44%	0.17%
15	total	0.212	33300	7940	116	7.17%	0.28%
15	particulate	0.0820	200	180	116	2.77%	0.11%
17	Dissolved	0.0920	66200	21000	252	1.36%	0.05%
17	total	0.384	65700	21000	250	5.72%	0.22%
17	particulate	0.292	-	0.00	250	4.35%	0.17%
19	Dissolved	0.0950	34000	14600	145	2.53%	0.10%
19	total	0.729	33700	14500	144	19.50%	0.76%
19	particulate	0.634	-	-	144	17.00%	0.66%
20	Dissolved	0.0980	49300	29600	245	1.49%	0.06%
20	total	0.176	49100	29600	244	2.69%	0.11%
20	particulate	0.0780	-	0.00	244	1.19%	0.05%
24	Dissolved	0.0320	64400	34700	303	0.39%	0.02%
24	total	0.236	66800	35600	313	2.78%	0.11%
24	particulate	0.204	2400	900	313	2.40%	0.09%
26	Dissolved	0.0170	57000	24000	241	0.26%	0.01%
26	total	0.121	56900	24200	241	1.87%	0.07%
26	particulate	0.104	-	200	241	1.61%	0.06%
27	Dissolved	0.0410	48500	28800	239	0.64%	0.02%
27	total	0.215	49600	29600	245	3.27%	0.13%
27	particulate	0.174	1100	800	245	2.65%	0.10%
30	Dissolved	0.139	40200	13900	158	3.37%	0.13%
30	total	0.417	39400	13600	154	10.40%	0.41%
30	particulate	0.278	-	-	154	6.93%	0.27%

31	Dissolved	0.152	50900	25300	231	2.46%	0.10%
31	total	0.195	52200	26000	237	3.07%	0.12%
31	particulate	0.0430	1300	630	237	0.68%	0.03%
33	Dissolved	0.0816	67800	20000	251	1.21%	0.05%
33	total	0.207	68400	20200	254	3.03%	0.12%
33	particulate	0.125	650	170	254	1.84%	0.07%
34	Dissolved	0.101	32900	6360	108	3.69%	0.14%
34	total	0.258	33000	6380	109	9.33%	0.36%
34	particulate	0.157	90	20	109	5.68%	0.22%
39	Dissolved	0.151	66100	28100	280	2.00%	0.08%
39	total	0.310	67200	28600	285	4.02%	0.16%
39	particulate	0.159	1160	530	285	2.06%	0.08%
41	Dissolved	0.0861	48800	22200	213	1.52%	0.06%
41	total	0.216	50800	23100	222	3.65%	0.14%
41	particulate	0.130	2000	860	222	2.19%	0.09%
42	Dissolved	0.0443	61000	18700	229	0.72%	0.03%
42	total	0.306	62900	19300	236	4.84%	0.19%
42	particulate	0.262	1840	610	236	4.14%	0.16%

Figure 23: Table showing the lead, calcium, and magnesium concentrations with the calculated hardness and percentage of toxicity for both chronic and acute toxicity criterias of samples taken from the tributaries. The element concentrations are given in ppb, and the hardness is in mg/L.

Like with the Lehigh River samples, this dataset was then plotted. The percentage of chronic toxicity was plotted against the channel distance from Palmerton to where the tributary connected with the Lehigh River. This is shown in the figure below:

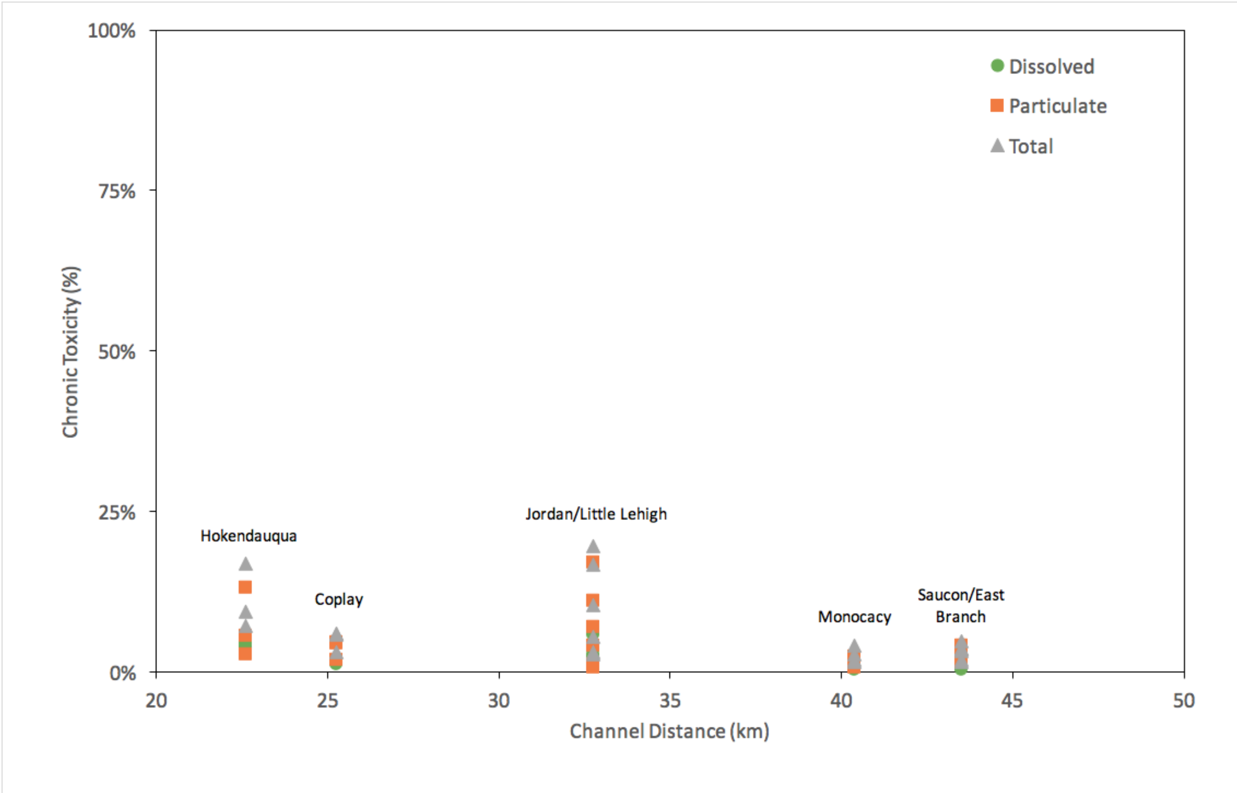


Figure 24: Dissolved, particulate, and total lead toxicity values plotted against the channel distance from the sample site to Palmerton for samples taken from the Lehigh River's tributaries. The chronic toxicity percentages for the tributaries are much lower than those for the Lehigh River. None of these values cross the toxicity threshold of 100% toxicity.

The greatest toxicity values from each site were mapped, and are shown below:

Greatest Toxicity Values

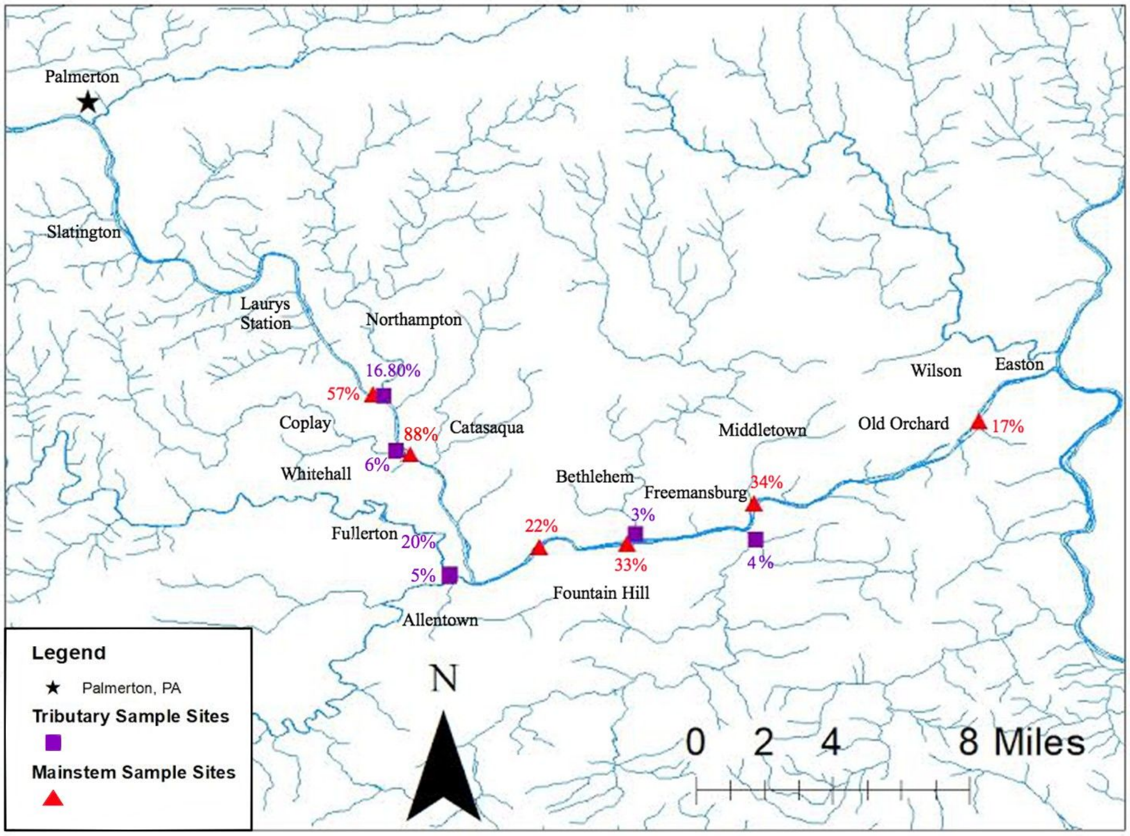


*Figure 25: Map showing the greatest toxicity values reached for each sample site. The tributary values are lower than most of the values from the Lehigh River (*United States Census Bureau*, n.d.,* PASDA*, n.d.).*

Discussion

The majority of data shows that lead in the Lehigh River is travelling mainly in the particulate form. While some samples from the Lehigh River showed a greater concentration of dissolved than particulate lead, this did not correlate with any one sampling date or location. The lead content of the tributaries flowing into the Lehigh River showed the same pattern, with a majority of the samples having a greater particulate than dissolved lead concentration. This particulate concentration of lead in the Lehigh River does not show a decrease with distance from Palmerton, but instead when all three sampling dates are combined, shows a slight increase. However, this increase for all three sample dates is not statistically significant. While the samples taken on June 19th show a slight decrease with distance in particulate lead concentration, the samples taken on July 2nd and July 19th show an increase with distance. The dissolved concentrations for lead for all three sample dates, however, show a statistically significant decrease with distance from Palmerton. When broken down by sample date, all three show a decrease in lead concentration with distance. They also show that as one moves closer to Palmerton, the dissolved lead concentrations are increasing overall.

The decrease in dissolved lead concentrations with distance is indicative of an upstream source. As shown in the flux diagrams, the discharge of the Lehigh River increases as the water flows downstream of Palmerton, and the flux of the dissolved lead decreases. This indicates that the dissolved lead is being diluted by the increase in discharge. The increase in particulate lead concentrations and increase in the flux of particulate lead as the water travels downstream may also contribute to the decrease in dissolved lead. The dissolved lead can be converted into particulate lead as it travels downstream, leading to a decrease in dissolved lead and an increase in particulate lead. This again implies that more dissolved lead is not being added significantly to the water, as it continues to decrease downstream without being sufficiently replenished, and is indicative of an upstream source of lead. The flux diagrams created also show that the main source of lead is not any of the tributaries sampled. For both the particulate and dissolved lead concentrations, the tributaries contributed very little lead compared to the flux of the Lehigh River, showing that the main source is likely at a point upstream of the river. This source could potentially be the Palmerton zinc companies, but this cannot be said with certainty. There are a number of other potential contributors of lead to the Lehigh River located upstream of the sample sites, such as car dealerships and battery plants. The source of lead could be any or all of these sites, and more sampling is needed. The lead could also potentially be coming from the sediments in the area if they contain lead. This is another area of study that should be further explored.

The lead was also determined to be correlating with the elements zinc, aluminum, manganese, and iron. Zinc is expected to be seen travelling with lead if its source is the zinc companies in Palmerton. The zinc concentrations, when compared to the lead concentrations, have moderate R^2 values and statistically significant p-values, indicating that there is a significant trend between them. However, the particulate concentrations have a stronger correlation than the dissolved concentrations. Aluminum also shows a significant correlation with the particulate lead concentrations. However, it does not have a significant correlation with the dissolved concentrations. Like zinc, manganese shows a correlation with lead in both its dissolved and particulate forms. However, when compared to the other studied elements, its correlation with lead is weaker. Iron shows a strong significant correlation with lead in its particulate form. However, there is not a significant correlation in the dissolved forms.

As observed in the flux diagrams, the main source of the fluxes of the dissolved elements are upstream of the Lehigh River, as the tributaries and groundwater contribute little to no concentrations. They also show that the dissolved concentrations of zinc and iron decrease, but only very slightly. Aluminum and manganese actually increase slightly in their dissolved concentrations between sample sites 1 and 5 and 6. However, this increase is very slight and may be due to the limits in the measurement of the concentrations.

The particulate flux diagrams also show that a majority of the concentrations are present in the Lehigh River itself and that the tributaries and groundwater/conversion from dissolved to particulate form do not contribute a majority of the concentrations. However, zinc is the exception to this. For zinc, the groundwater/conversion from the dissolved load is actually greater than the concentrations present at site 1. To determine whether or not the source is groundwater or the conversion from dissolved to particulate form, further data would need to be collected. While a groundwater source could indicate that the majority of the zinc is not necessarily coming from a point upstream, the source of the additional zinc could also be the conversion of the dissolved load. The particulate lead concentration shows a similar pattern. While the majority of the particulate lead measured at sites 5 and 6 was already present at site 1, the groundwater/conversion from dissolved load does contribute a large amount. Zinc and iron also show an increase in their particulate concentrations between sample site 1 and samples sites 5 and 6, aluminum shows a very slight increase, and manganese shows a slight decrease.

This similarity between lead and zinc indicates that they are travelling together. The elements studied are elements commonly originating from factory plants and other human manufacture waste, and zinc especially is indicative of pollution from the zinc companies. However, while this does support the possibility of the Palmerton zinc company being a source of the lead, there are multiple possible sources upstream of the Lehigh River that could also be a source for these elements. Further sampling of Palmerton and the areas upstream of it is needed.

The lead content of the Lehigh River and its tributaries was found to be below the toxicity levels for humans and for aquatic organisms. The EPA sets the amount of lead that is harmful to humans and requires action at 15 ppb (*United States Environmental Protection Agency*, n.d. b.), and all of the lead concentrations are well below this. The acute and chronic toxicity criteria for aquatic animals were also calculated, and none of the lead concentrations exceeded the criteria. The closest any of the samples from the Lehigh River got to exceeding the criteria was at sample site 2, which is located near Whitehall and had a chronic toxicity of 88%. The toxicity percentages from the Lehigh River show an overall decrease with the distance of the sample sites from Palmerton. However, calcium increases with distance from Palmerton, which would increase the hardness and the amount of lead that can be in the water without it being toxic. The highest toxicity from the tributary samples was at Jordan Creek, but this only reached about 20%. All of the water is safe for consumption by humans and aquatic animals.

Studies similar to this one have been conducted all over the world. One such study was conducted on two rivers in Japan. Both rivers are located in areas with volcanic rocks along rice paddy fields in the Yatsugatake-Chūshin Kōgen Quasi-National Park. Most importantly, there is not an industrial area upstream of the rivers, so the lead in these rivers is not coming from an anthropogenic industrial source. The scientists found that a majority of the lead was travelling in the particulate form with iron, aluminum, and titanium (*Nakaya et. al.*, 2018). This matches what was found in this study, as aluminum, manganese, and iron all had high correlations with the lead concentrations overall. However, zinc was not measured in the study in Japan. Titanium was also found to have a high correlation in both studies, but unfortunately was not graphed because titanium concentrations were not obtained for all three sample dates in this study. This study also shows that the lead concentrations of the Lehigh River were lower than those of the two rivers sampled, River A and River Y, in the study in Japan. This data was graphed against the data from the Lehigh River, and is shown below:

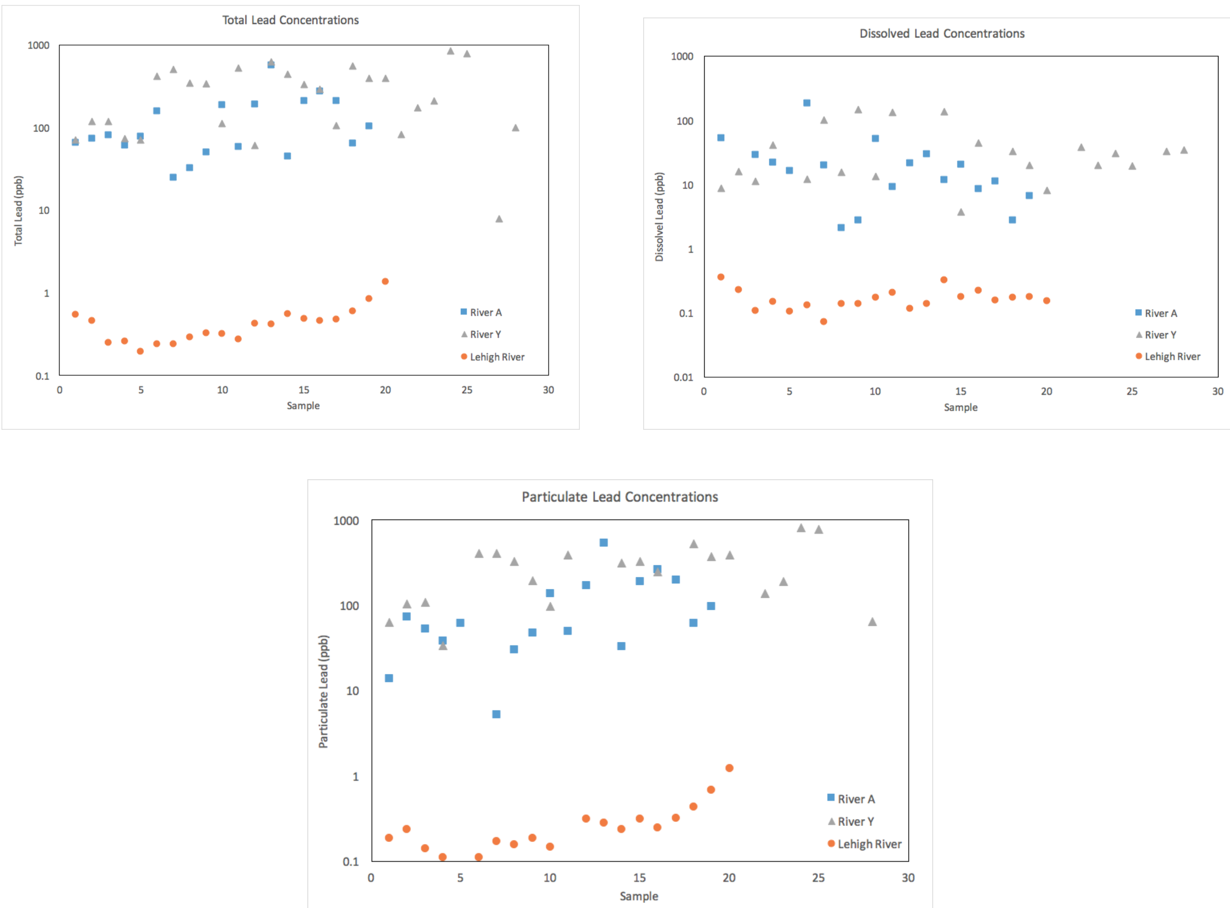


Figure 26: Total, dissolved, and particulate concentrations for lead in the Lehigh River compared to the two rivers in Japan (Nakaya et. al., *2018*).

The Lehigh River has a much lower concentration of lead in all three forms than Rivers A and Y. The concentrations of lead can also be averaged to show how the three compare:

River	Dissolved Pb	Particulate Pb	Total Pb
River A	26.505	107.521	134.026
River Y	80.607	220.501	301.512
Lehigh River	0.173	0.234	0.408

Figure 27: The dissolved, particulate, and total concentrations of lead for the three rivers (Nakaya et. al., *2018*).

As shown in the table, the Lehigh River has a much lower concentration of lead than the other two rivers in this study. It should be noted that this study used a 0.1 μm filter as opposed to the 0.2 μm filter used on the Lehigh River samples, so some variation between dissolved and particulate forms is expected.

The concentrations of lead in the Lehigh River can also be compared to those of Flint, Michigan, which is known for its recent lead contamination. A state of emergency was declared in 2016 when dangerous levels of lead were found in the residents' tap water. At least 25% of the residences had concentrations of lead above 15 ppb, and some even had concentrations as high as 13,200 ppb (*Lazarus*, 2016). This is much higher than the lead found in this study to be in the Lehigh River, which only reaches about 2 ppb at a maximum. The lead levels recorded by the government can be compared to those in the Lehigh River, which is shown below:

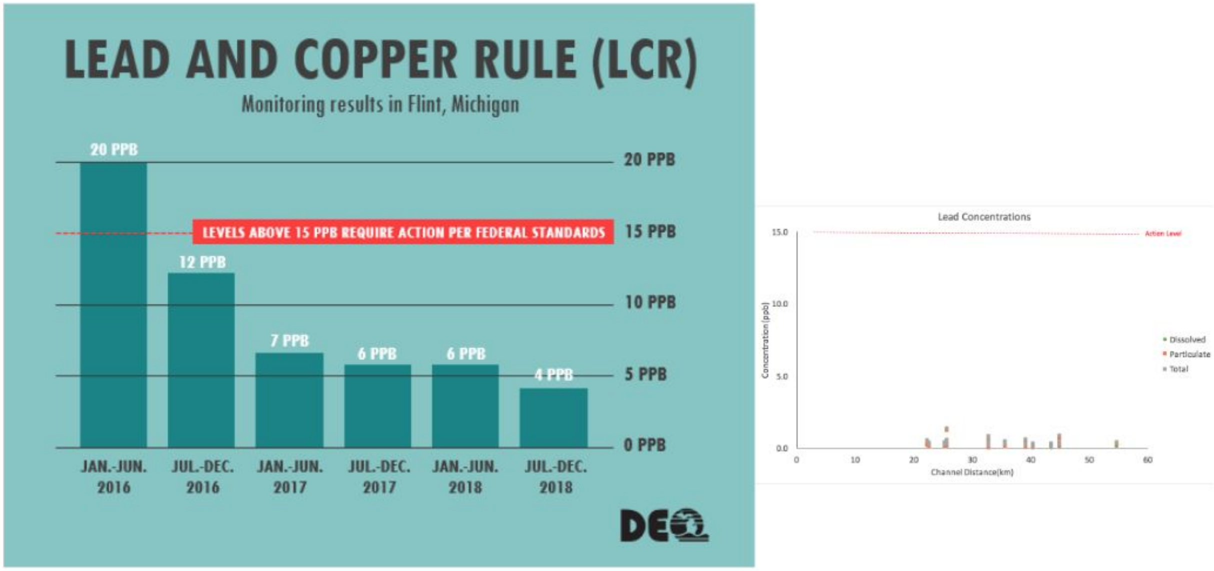


*Figure 28: Side-by-side comparison of the levels of lead present in Flint, Michigan (left) (*Michigan.gov *2019) and the Lehigh River (right). Those in the Lehigh River are well below the action level of 15 ppb, but Flint exceeded this in 2016 and continued to have higher lead levels than the Lehigh River in 2018.*

When compared to other water sources in the world, the Lehigh River has a very low amount of lead.

Further research on the Lehigh River could be conducted to better determine the origin of the lead concentrations. Samples should be taken upstream of Palmerton to better determine if this area is the source. Unfortunately there was an abnormal amount of rainfall during the timeframe of this study, which caused very high flow conditions that would not have yielded useful data. More water samples can be collected once the flow rates return to normal. Sediment data can also be collected to determine if the source of the lead is anthropogenic, or if it is from the sediments in the area.

Conclusions

This study shows that the dissolved lead content of the Lehigh River decreases downstream from Palmerton and increases closer to it. This, coupled with its correlation with the anthropogenic elements zinc, aluminum, manganese, and iron, suggest an anthropogenic source upstream of the sample sites. The tributaries feeding into the Lehigh River along the sample sites do not show a significant contribution of lead or the other elements, ruling them out as the main source of the lead. While the data does suggest that Palmerton is a potential source of the lead content, many other possible sources of lead and these other elements exist upstream of the sample sites. Further study, such as collecting samples from the Lehigh River and its tributaries upstream of Palmerton, is needed to determine an exact upstream source. Sediment data can also be collected to determine if the majority of lead is coming from an anthropogenic source or if it is instead coming from the sediments. Additionally, more accurate discharge and flux values can be obtained by measuring the tributaries when flow conditions are more favorable, as unfortunately using programs like Google Earth and Caltopo, while giving an approximation, do not achieve the most accurate calculations. This study also shows that none of the sample locations of the Lehigh River nor its sampled tributaries have levels of lead toxic to humans and aquatic animals. The data shows that the lead is likely originating from an upstream source and that it is not hazardous.

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Additional Data

The concentrations of several elements were obtained for each sample, and not all of them were analyzed in this study. All of the elemental concentrations for the samples run in Lehigh's ICP-MS are shown below (the first two rounds of sampling).

Sample Number	7Li	9Be	11B	23Na	24Mg	27Al	29Si	39K	43Ca	44Ca	47Ti	51V	52Cr	55Mn	56Fe	59Co
	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
0254-002-Dissolved	2.66	0.094	9.65	11300	4050	60.6	1480	1020	9400	10000	0.338	0.23	0.32	22.1	68.9	0.231
0254-002-Total	2.67	0.071	10.2	11600	4080	80.8	1470	1110	9320	9780	0.659	0.228	0.423	28.6	119	0.354
0254-003-Dissolved	1.15	0.019	28.3	31500	21200	-6.62	2540	4690	64200	66700	1.37	0.6	1.74	8.6	15.7	0.1
0254-003-Total	1.12	0.023	28.5	32800	21800	22.1	2690	4770	65000	68100	2.22	0.647	1.88	16	89.3	0.155
0254-004-Dissolved	2	0.071	11.4	13200	6400	51.9	1730	1390	14800	15700	0.458	0.241	0.597	17.8	61.4	0.211
0254-004-Total	2.01	0.078	10.9	13600	6580	75.7	1890	1360	15300	16100	0.715	0.251	0.57	24.7	112	0.315
0254-005-Dissolved	0.344	0.016	14.4	37200	18700	-6.03	1690	2540	42200	43700	1.11	0.843	1.25	14.1	31.7	0.103
0254-005-Total	0.271	0.032	14.3	38000	18900	10.3	1940	2350	43000	44600	1.64	0.881	1.53	16.5	71.7	0.11
0254-006-Dissolved	2.1	0.013	17.4	34400	27100	-10.5	3910	2680	46100	48200	0.997	0.686	2.34	7.96	30.3	0.077
0254-006-Total	2.1	0.01	17.6	35100	27400	7.73	4160	2580	46700	48400	1.71	0.664	2.61	9.77	80.4	0.08
0254-007-Dissolved	1.64	0.026	17.2	25200	10500	65	2140	2000	20300	21100	0.896	0.393	0.883	14.3	70.9	0.694
0254-007-Total	1.64	0.042	16.9	26500	10700	83.7	2490	2030	20800	21500	1.18	0.407	0.942	20.5	111	0.828
0254-007dup-Dissolved	1.69	0.045	17.5	25100	10500	63.6	2150	2000	20600	20700	0.735	0.372	0.823	14.2	71.1	0.706
0254-007dup-Total	1.67	0.091	17.2	25500	10300	75.4	2160	1950	20100	20300	1.2	0.404	0.907	19.5	116	0.796
0254-008-Dissolved	0.422	0	18	36000	32200	-10.2	3900	9450	62300	64900	1.31	0.484	2.05	5.34	18.5	0.088
0254-008-Total	0.415	-0.01	18.4	37100	32800	-0.375	4270	9600	64300	66400	1.46	0.502	2.42	6.52	52.5	0.1
0254-009-Dissolved	0.303	0.013	18	37000	32800	-10.9	4000	9640	63000	66200	1.49	0.489	2.25	5.34	21.7	0.091
0254-009-Total	0.326	0.032	18.1	36800	32900	4.86	4130	9720	63500	65800	2.19	0.493	2.32	6.64	50.9	0.1
0254-010-Dissolved	1.46	0.049	15.1	20800	9220	80.3	1990	1740	17600	18300	0.699	0.351	0.776	17.2	85.1	0.442
0254-010-Total	1.43	0.062	15.1	20800	9340	97.4	2010	1710	17200	18500	0.84	0.374	0.77	25.1	127	0.596
0254-011-Dissolved	-0.915	-0.003	-0.11	98.3	23.8	-14.4	-373	57	26.1	36	0.048	0.065	0.172	0.19	16.2	-0.002
0254-011-Total	-0.87	0.003	-0.588	247	5.05	-14.8	-365	17	-14.1	0.172	-0.056	0.015	0.074	0.118	14.6	-0.001
0254-012-Dissolved	3.2	0.013	21.9	22300	26000	-11.7	7040	3370	44000	45500	1.11	1.01	1.67	11.4	35.6	0.08
0254-012-Total	3.09	0.039	21.5	22200	25900	13.4	7060	3340	44000	45800	2.19	1.08	1.71	14.8	90	0.094
0254-013-Dissolved	7.76	0.006	61.3	23400	21100	-4.03	9190	10100	48200	50000	1.21	6.42	5.01	12.7	75.3	0.122
0254-013-Total	7.73	0.016	61.9	22500	20600	10.8	9010	9580	47300	48700	1.74	6.38	4.77	15.4	136	0.124
0254-014-Dissolved	1.37	0.042	18.2	22700	11400	72.7	2180	2350	21700	21200	0.767	0.432	0.866	12.6	69.8	0.395
0254-014-Total	1.39	0.074	17.4	23200	11700	87.8	2340	2400	22200	22000	1.39	0.455	0.881	20.2	127	0.524
0254-014dup-Dissolved	1.34	0.042	17.2	23300	11700	75.1	2220	2360	21200	21400	0.743	0.43	0.874	12.9	73.9	0.41
0254-014dup-Total	1.38	0.039	16.8	23200	11600	88.9	2240	2350	21900	22100	1.77	0.471	0.9	20.3	128	0.512

Sample Number	60Ni	65Cu	66Zn	75As	82Se	85Rb	88Sr	90Zr	95Mo	107Ag	111Cd	118Sn	121Sb	133Cs	137Ba	202Hg	205Tl	206Pb	208Pb
	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
0254-002-Dissolved	2.55	1.27	21.4	0.162	0.295	1.89	75.7	0.092	0.711	0.001	0.138	0.09	0.081	0.043	22.5	1.9	0.012	0.297	0.359
0254-002-Total	3.05	1.83	30.3	0.151	0.281	1.97	74.5	0.106	0.717	0	0.184	0.173	0.083	0.046	23	0.803	0.015	0.585	0.546
0254-003-Dissolved	0.926	0.839	4.06	0.326	0.63	6.04	352	0.04	0.406	-0.001	0.02	0.213	0.146	0.066	30.4	1.19	0.015	0.115	0.092
0254-003-Total	0.971	2.31	5.48	0.36	0.692	6.1	357	0.05	0.424	-0.001	0.017	0.166	0.167	0.066	30.9	0.646	0.019	0.481	0.418
0254-004-Dissolved	2.46	1.71	19.3	0.167	0.314	2.43	97.7	0.047	0.618	-0.001	0.137	0.693	0.088	0.048	22.9	0.08	0.002	0.25	0.227
0254-004-Total	2.57	1.46	23.6	0.18	0.338	2.51	101	0.045	0.668	-0.001	0.15	0.147	0.085	0.053	23.9	-0.037	0.002	0.477	0.466
0254-005-Dissolved	0.706	1.6	10.6	0.25	0.492	1.82	135	0.059	1.36	0	0.023	0.2	0.186	0.013	26.9	-0.004	0.01	0.294	0.283
0254-005-Total	0.606	1.61	9.03	0.261	0.49	1.71	138	0.035	1.57	-0.001	0.017	0.085	0.187	0.013	26.6	-0.119	0.024	0.777	0.833
0254-006-Dissolved	0.607	0.913	7.1	0.2	0.398	2.9	113	0.034	0.18	-0.001	0.037	0.187	0.084	0.023	36.9	-0.217	0.012	0.08	0.08
0254-006-Total	0.674	1.21	8.17	0.225	0.449	2.82	114	0.03	0.219	0	0.019	0.118	0.072	0.025	37.8	-0.246	0.007	0.325	0.335
0254-007-Dissolved	2.13	1.69	11.4	0.152	0.288	2.98	99	0.04	0.819	-0.001	0.081	0.048	0.112	0.066	24	-0.217	0.007	0.12	0.108
0254-007-Total	2.22	2.08	19.5	0.174	0.321	3.05	103	0.049	0.926	0.001	0.103	0.056	0.125	0.064	24.1	-0.267	0	0.311	0.251
0254-007dup-Dissolved	2.09	1.63	11.4	0.159	0.302	2.98	98.4	0.047	0.803	-0.001	0.078	0.043	0.124	0.054	23.4	-0.335	0.019	0.146	0.151
0254-007dup-Total	2.12	2.01	18.9	0.161	0.305	2.9	96.3	0.039	0.855	0.001	0.095	0.04	0.108	0.062	23.9	-0.317	0.005	0.297	0.263
0254-008-Dissolved	0.772	1.24	3.08	0.512	1.07	23.7	254	0.018	0.288	-0.001	0.012	0.082	0.079	0.263	37.4	-0.362	0.015	0.054	0.036
0254-008-Total	0.635	1.41	5.26	0.559	1.17	24.2	261	0.06	0.322	-0.001	0.006	0.037	0.065	0.28	37.6	-0.401	0.01	0.18	0.151
0254-009-Dissolved	0.659	1.33	7	0.544	1.13	23.6	257	0.032	0.29	-0.001	0.01	0.102	0.061	0.268	37.8	-0.375	0.007	0.049	0.064
0254-009-Total	0.671	1.39	6.2	0.555	1.16	24.1	256	0.022	0.277	-0.001	0.005	0.022	0.057	0.279	37.6	-0.406	0.017	0.149	0.124
0254-010-Dissolved	2.16	1.66	18.7	0.151	0.291	2.85	94.7	0.048	0.787	-0.001	0.07	0.061	0.095	0.06	23.3	-0.403	0.005	0.143	0.104
0254-010-Total	2.24	1.64	20.7	0.133	0.243	2.84	94.7	0.035	0.751	-0.001	0.09	-0.018	0.093	0.06	24.1	-0.442	0.017	0.251	0.195
0254-011-Dissolved	0.001	0.386	3.54	-0.056	-0.116	0.056	0.163	0.001	-0.01	-0.001	0.006	0.129	-0.006	-0.002	0.052	-0.516	0	0.005	0.012
0254-011-Total	0.123	0.153	1.97	-0.066	-0.138	0.016	0.009	0.003	-0.016	0.003	0.01	0.124	-0.001	-0.001	0.056	-0.567	-0.002	0.051	0.04
0254-012-Dissolved	0.506	1.43	12	0.238	0.448	3.91	129	0.033	0.736	-0.001	0.027	0.011	0.093	0.022	39.3	-0.496	0.012	0.061	0.068
0254-012-Total	0.472	1.56	11.5	0.248	0.46	3.97	130	0.138	0.778	-0.002	0.019	-0.012	0.093	0.023	40	-0.553	0.015	0.225	0.215
0254-013-Dissolved	0.785	1.04	11.6	0.439	0.898	19.1	161	0.077	9.4	-0.001	0.03	0.113	0.102	0.11	28	-0.36	0.005	0.079	0.108
0254-013-Total	0.613	0.663	2.93	0.383	0.784	18.3	155	0.024	9.12	-0.002	0.011	-0.023	0.096	0.107	27	-0.351	0.01	0.067	0.088
0254-014-Dissolved	1.94	1.61	13.5	0.134	0.239	3.81	98.3	0.025	0.795	-0.001	0.048	-0.007	0.105	0.066	23.9	-0.529	0.002	0.123	0.132
0254-014-Total	2.17	1.68	18.2	0.117	0.223	3.89	102	0.046	0.754	-0.001	0.068	-0.014	0.112	0.07	24.8	-0.547	0.01	0.273	0.243
0254-014dup-Dissolved	2.02	1.63	13.8	0.123	0.235	3.88	101	0.032	0.816	-0.001	0.051	-0.021	0.103	0.062	23.9	-0.516	0.005	0.131	0.072
0254-014dup-Total	2.25	1.74	18.4	0.133	0.248	3.88	103	0.054	0.748	-0.001	0.071	-0.008	0.11	0.069	25.2	-0.517	0.012	0.279	0.243

Sample Number	7Li	9Be	11B	23Na	24Mg	27Al	29Si	39K	43Ca	44Ca	47Ti	51V	52Cr	55Mn	56Fe	59Co
	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
0254-015-Dissolved	0.54	-0.027	13.3	26400	7760	12.9	2750	7300	30000	33100	0.142	0.692	0.348	14	43.9	0.11
0254-015-Total	0.404	-0.028	13.8	26500	7940	29.7	2930	7390	29700	33300	0.628	0.481	0.393	17.5	72.4	0.125
0254-016-Dissolved	2.68	0.059	7.03	12000	4180	72.4	1510	930	8770	10100	0.048	0.288	0.214	20.1	75.5	0.172
0254-016-Total	2.72	0.102	6.91	12100	4110	101	1530	927	8780	10000	0.441	0.263	0.201	37.6	123	0.516
0254-017-Dissolved	1.35	-0.017	17.4	32600	21000	6.39	3180	4880	60400	66200	0.282	0.847	0.391	7.27	10.4	0.116
0254-017-Total	1.28	-0.009	19.4	32500	21000	42.3	3420	4720	59100	65700	0.906	0.682	1.42	13.5	47.8	0.166
0254-018-Dissolved	2.25	0.036	8.3	13400	6170	62	1780	1270	13900	15900	0.07	0.422	0.53	23.4	56.5	0.163
0254-018-Total	2.37	0.082	7.85	13400	6120	196	2140	1220	13900	16000	2.57	0.465	0.625	67.1	247	0.814
0254-019-Dissolved	0.171	-0.011	9.77	25000	14600	3.66	3280	2330	30300	34000	0.243	0.606	1.06	7.52	14.1	0.074
0254-019-Total	0.142	-0.021	10.3	25500	14500	30.4	3300	2540	30400	33700	0.868	0.626	1.14	15.2	54.6	0.126
0254-020-Dissolved	2.82	-0.023	9.18	35500	29600	0.073	2410	2700	46700	49300	0.099	0.526	1.12	6.98	8.57	0.064
0254-020-Total	2.84	-0.015	11.5	35400	29600	8.39	2920	2500	46100	49100	0.446	0.532	2.37	7.6	24.3	0.065
0254-021-Dissolved	2.27	0.038	11.9	22300	9840	47.6	2050	1900	17800	20300	0.31	0.391	0.815	19.3	55.1	0.619
0254-021-Total	2.26	0.042	11.9	22300	9840	67.3	2070	1890	17900	20400	0.64	0.401	0.725	25.8	85.7	0.753
0254-022-Dissolved	-0.849	-0.042	0.107	238	13.1	-2.5	-549	80.9	-43.5	8.96	-0.357	0.064	0.019	0.149	-14.6	-0.023
0254-022-Total	-0.777	-0.051	-0.469	87.5	2.47	-2.25	-531	33.9	-79	-16.9	-0.348	0.015	-0.007	-0.002	-16.4	-0.026
0254-023-Dissolved	2.28	0.057	11.5	22900	9900	46.2	2100	2090	17900	20100	0.323	0.383	0.801	19.4	52.7	0.658
0254-023-Total	2.26	0.04	11.4	22200	9910	66.4	2210	1850	17500	19900	0.544	0.371	0.743	26.3	87.6	0.76
0254-024-Dissolved	0.681	-0.006	10.7	37600	34700	-0.392	3920	7030	59700	64400	0.075	0.478	1.55	5.86	-7.25	0.077
0254-024-Total	0.691	-0.027	9.03	38400	35600	12	3760	7070	60700	66800	0.289	0.475	0.73	7.57	10.6	0.096
0254-025-Dissolved	2.04	0.047	9.9	19500	9120	53.6	1820	1790	16000	18500	0.213	0.347	0.241	18.3	48.1	0.413
0254-025-Total	2.12	0.063	10	20100	9430	70.4	1940	1710	16600	19100	0.559	0.366	0.235	25.2	80.6	0.535
0254-026-Dissolved	11.4	-0.03	49.4	22900	24000	5.75	8280	11200	50800	57000	0.275	5.75	3.88	10.6	7.32	0.096
0254-026-Total	11.5	-0.027	52.9	23100	24200	18.9	8330	11200	51300	56900	0.811	6.05	4.98	14.7	69.3	0.111
0254-027-Dissolved	4.14	-0.019	16.1	19800	28800	-1.15	6070	3210	44500	48500	0.27	0.776	1.51	9.36	-4.87	0.059
0254-027-Total	4.04	-0.008	14.8	20200	29600	19.2	6100	3220	44400	49600	0.883	0.777	1.68	13.6	26.7	0.074
0254-028-Dissolved	1.98	0.009	11.2	21100	11000	48.6	2000	2190	18100	21300	0.149	0.374	0.352	13.3	37.7	0.346
0254-028-Total	2	0.055	11.4	21000	11000	78.1	2060	2170	18400	21200	0.612	0.404	0.544	25.4	84.6	0.569
0254-029-Dissolved	1.95	0.03	11	22200	11400	38.1	2080	2220	18600	21800	0.176	0.399	0.229	23.5	41.8	0.534
0254-029-Total	1.92	0.023	10.6	21500	11200	64.2	2110	2180	18700	21700	0.474	0.429	0.277	32.7	92.2	0.703
0254-001-Dissolved	-0.303	-0.021	11.5	21800	7110	3.56	1900	5140	22700	26300	-0.164	0.388	0.426	9.57	12	0.046
0254-001-Total	-0.322	-0.025	11.8	21600	6960	31.6	2090	5070	22400	26000	0.322	0.376	0.538	15.1	66.6	0.079

Sample Number	60Ni	65Cu	66Zn	75As	82Se	85Rb	88Sr	90Zr	95Mo	107Ag	111Cd	118Sn	121Sb	133Cs	137Ba	202Hg	205Tl	206Pb	208Pb
	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
0254-015-Dissolved	2.1	1.76	10.7	0.389	0.25	27.9	219	0.083	0.35	0.001	0.02	0.058	0.093	0.384	16.1	2.4	0.004	0.135	0.13
0254-015-Total	0.888	1.73	6.06	0.386	0.177	28.2	224	0.056	0.335	-0.001	0.023	0.012	0.092	0.395	16.4	0.831	0.005	0.21	0.212
0254-016-Dissolved	2.81	1.21	20.6	0.25	0.049	1.62	68.3	0.045	0.628	-0.001	0.125	-0.024	0.062	0.032	20.4	0.234	0.004	0.141	0.137
0254-016-Total	3.15	1.4	26.4	0.32	0.154	1.6	68.3	0.043	0.597	-0.001	0.176	-0.017	0.06	0.032	20.9	0.054	0.004	0.282	0.294
0254-017-Dissolved	1.75	0.784	4.15	0.504	0.403	5.53	333	0.045	0.373	-0.002	0.059	0	0.13	0.054	26.9	0.267	0.021	0.095	0.092
0254-017-Total	0.972	0.706	4.53	0.537	0.332	5.38	327	0.037	0.349	-0.002	0.01	-0.012	0.129	0.058	26.5	0.036	0.022	0.377	0.384
0254-018-Dissolved	2.11	1.09	13.8	0.318	0.108	2.3	88.2	0.024	0.542	-0.002	0.058	0.009	0.064	0.044	19.3	-0.127	0.004	0.158	0.152
0254-018-Total	2.83	1.71	27	0.403	0.101	2.41	89.6	0.081	0.495	-0.002	0.17	-0.036	0.07	0.06	22	-0.243	0.007	1.32	1.38
0254-019-Dissolved	0.934	0.771	3.83	0.409	0.096	1.38	116	0.015	3.57	-0.002	0.021	-0.039	0.072	0.003	18.9	-0.184	0.009	0.099	0.095
0254-019-Total	0.591	1.31	3.7	0.488	0.179	1.56	116	0.032	3.49	0	0.035	-0.026	0.08	0.006	19.6	-0.247	0.011	0.723	0.729
0254-020-Dissolved	0.696	0.775	7.2	0.21	0.237	2.57	107	0.012	0.146	0.001	0.011	-0.005	0.034	0.014	33.7	-0.263	0.004	0.103	0.098
0254-020-Total	0.634	0.381	0.633	0.179	0.134	2.36	106	0.004	0.114	-0.001	0.004	-0.029	0.026	0.015	33.4	-0.261	0.004	0.171	0.176
0254-021-Dissolved	2.08	1.4	13.5	0.291	0.083	2.53	89	0.03	0.735	-0.002	0.06	-0.035	0.071	0.044	22.5	-0.314	0.005	0.139	0.138
0254-021-Total	2.28	1.59	15.7	0.336	0.09	2.53	88.8	0.035	0.734	-0.002	0.079	-0.039	0.069	0.045	23	-0.315	0.005	0.313	0.326
0254-022-Dissolved	-0.076	0.124	3.53	0.031	-0.154	0.07	0.021	-0.008	-0.037	-0.001	0.004	-0.047	-0.005	-0.002	-0.386	-0.384	-0.003	0.024	0.017
0254-022-Total	-0.038	0.052	3.32	0.037	-0.215	0.027	-0.039	-0.009	-0.043	-0.002	-0.001	-0.045	-0.006	-0.002	-0.359	-0.405	-0.003	0.022	0.019
0254-023-Dissolved	2.43	1.87	17.9	0.302	0.134	2.69	88.3	0.037	0.725	-0.002	0.063	-0.005	0.078	0.045	22.6	-0.371	0.005	0.174	0.175
0254-023-Total	2.04	1.5	18.9	0.309	0.046	2.48	86.9	0.039	0.72	-0.002	0.078	-0.052	0.065	0.045	22.5	-0.344	0.005	0.315	0.322
0254-024-Dissolved	0.54	0.713	2.53	0.236	0.748	12.3	177	0	0.19	-0.002	0.003	-0.052	0.032	0.108	32.8	-0.358	0.009	0.036	0.032
0254-024-Total	0.557	0.902	2.7	0.277	0.898	12.5	185	0.004	0.174	-0.002	0.006	-0.041	0.032	0.113	33.9	-0.372	0.009	0.235	0.236
0254-025-Dissolved	1.93	2.24	19.1	0.295	-0.013	2.38	82.3	0.024	0.61	-0.001	0.06	0.056	0.071	0.041	21.8	-0.356	0.005	0.209	0.206
0254-025-Total	1.99	1.38	22.1	0.359	0.066	2.4	86.4	0.031	0.648	-0.002	0.074	-0.042	0.063	0.045	22.8	-0.385	0.005	0.27	0.277
0254-026-Dissolved	0.541	0.527	6.12	0.362	0.739	18.4	152	0.016	9.04	-0.002	0.01	-0.058	0.072	0.102	24.6	-0.262	0.008	0.024	0.017
0254-026-Total	0.513	0.645	6.45	0.393	0.694	18.4	154	0.012	9.15	-0.002	0.018	-0.022	0.074	0.103	25.2	-0.299	0.008	0.12	0.121
0254-027-Dissolved	0.375	1.16	6.67	0.408	0.336	3.35	118	0	0.562	-0.002	0.009	-0.046	0.028	0.015	33.3	-0.364	0.003	0.041	0.041
0254-027-Total	0.425	0.851	6.9	0.372	0.317	3.3	118	0.002	0.501	-0.002	0.019	-0.06	0.028	0.017	34	-0.396	0.003	0.213	0.215
0254-028-Dissolved	1.54	1.19	9.34	0.316	0.024	2.78	86.4	0.015	0.665	-0.002	0.035	-0.048	0.058	0.045	21.7	-0.402	0.004	0.122	0.116
0254-028-Total	1.75	1.42	18.2	0.381	0.161	2.83	87.5	0.028	0.649	-0.002	0.076	-0.044	0.065	0.047	22.6	-0.408	0.005	0.42	0.433
0254-029-Dissolved	1.66	1.28	11.4	0.359	0.035	2.73	83.8	0.017	0.625	-0.002	0.031	-0.049	0.068	0.043	23	-0.427	0.004	0.141	0.139
0254-029-Total	1.77	1.47	13.6	0.389	0.063	2.74	84.3	0.024	0.607	-0.002	0.061	-0.061	0.069	0.044	23.4	-0.412	0.006	0.415	0.424
0254-001-Dissolved	0.422	0.734	2.33	0.368	-0.039	17.8	149	0.002	0.209	-0.002	0.013	-0.016	0.072	0.26	12.8	-0.435	0.001	0.09	0.088
0254-001-Total	0.449	1.5	10.5	0.361	-0.074	17.7	148	0.01	0.199	-0.001	0.027	0.074	0.07	0.262	13.3	-0.422	0.002	0.375	0.393